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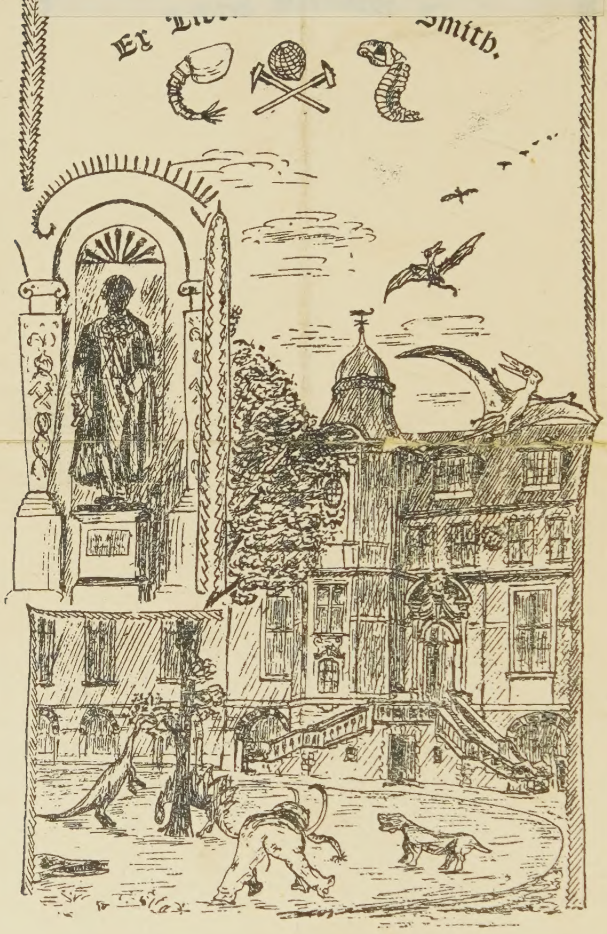

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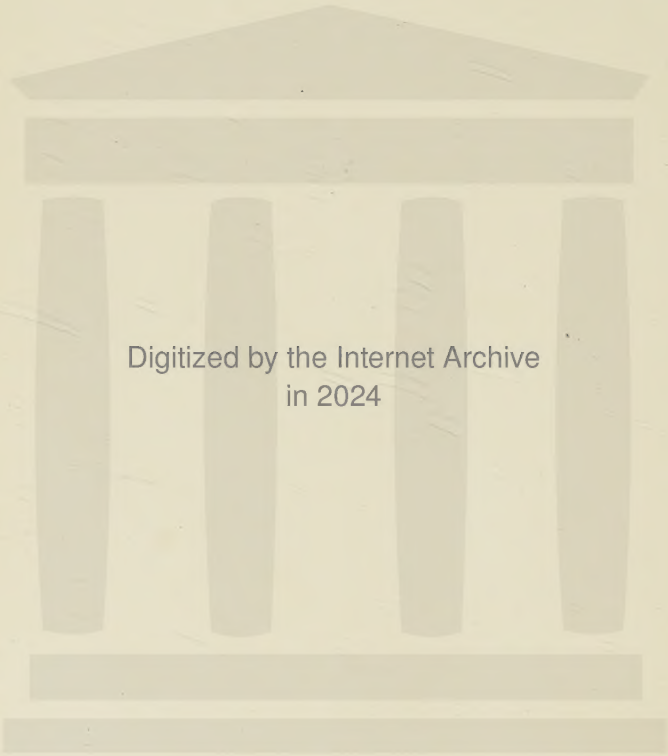
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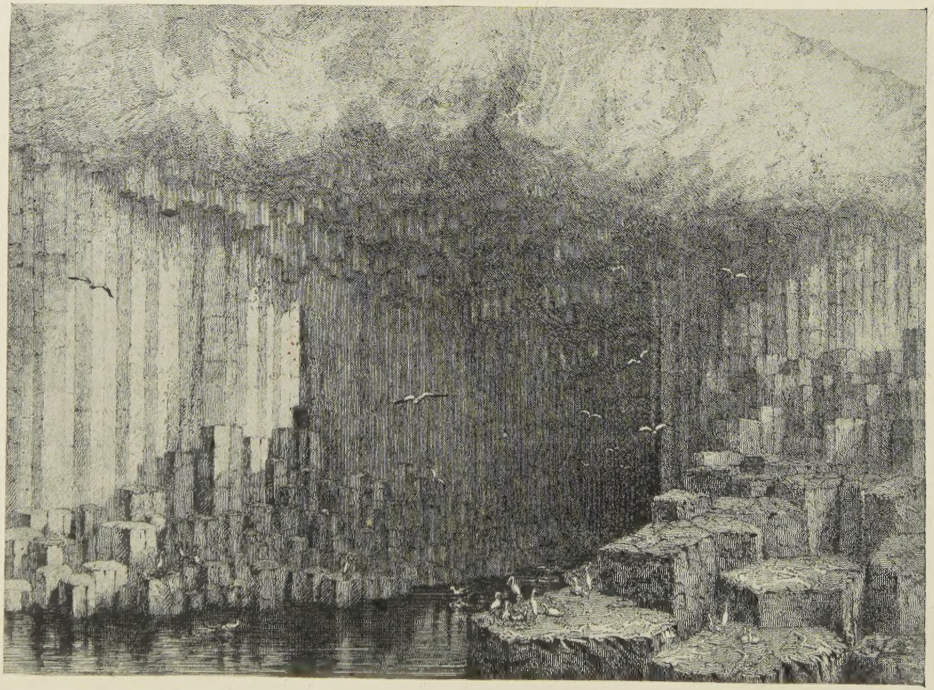
PHYSICAL GEOGRAPHY FOR SCHOOLS



FINGAL'S CAVE, STAFFA.

PHYSICAL GEOGRAPHY

FOR

SCHOOLS

BY

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Late Scholar of Sidney Sussex College, Cambridge; Harkness Scholar of the University of Cambridge (1906); Supplementary University Extension Lecturer, Cambridge and London; Late Examiner in Geography for the Cambridge Local Examinations

LONDON

ADAM AND CHARLES BLACK

1911

PREFACE

This book has been written for the use of students in the higher classes of our schools, where the cost and comprehensiveness of a larger text-book is prohibitive. At the same time it is hoped that the subject has been treated sufficiently fully and suggestively to meet the requirements of the teacher as well as the pupil. It was inevitable that the whole scope of the subject could not be satisfactorily dealt with in some 120 pages of text ; Part I., which belongs more to the realm of Astronomy and speculative Geology, has therefore been considerably curtailed, and the body of the work devoted to the more striking physical processes observable upon the surface of the earth. In Part VI. the connection between rock structure and the historical development of physical features is pointed out, and at intervals throughout the book, more particularly at the ends of the chapters, the question of environment—the interaction between Man and Nature—has been considered.

The illustrations have been chosen as much as possible from the British Isles, in order that students may learn to appreciate the physical characteristics of their own country. They have been drawn from many sources which are in most cases fully acknowledged. My thanks are due to many friends for furnishing me with hitherto unpublished photographs.

In the treatment of the subject no claim is laid to originality. I have availed myself fully of the writings of physiographers and geographers of world-wide repute. Amongst these works I might mention those of Dr. J. E. Marr ('Stratigraphical Geology' and 'Scientific Study of Scenery'), Sir A. Geikie ('Text-Book of Geology' and 'Ancient Volcanoes of Great Britain'), Lord Avebury ('Scenery of England and Wales'), H. J. Mackinder ('Britain and the British Seas'), Dr. H. R. Mill ('The International Geography'), Professor W. M. Davis ('Physical Geography,' etc.), Professor R. S. Tarr ('Elementary Physical Geography'), E. J. Jukes-Browne ('Stratigraphical Geology'), Professors Judd, Kirchhoff, Bonney, J. Geikie, Sollas, and Chamberlin.

I am also indebted to Mr. E. L. Guilford, M.A., for his kindness in carefully reading and checking the first proofs.

BERNARD SMITH.

November, 1910.

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PHYSICAL GEOGRAPHY.

CHAPTER I.

The Solar System.

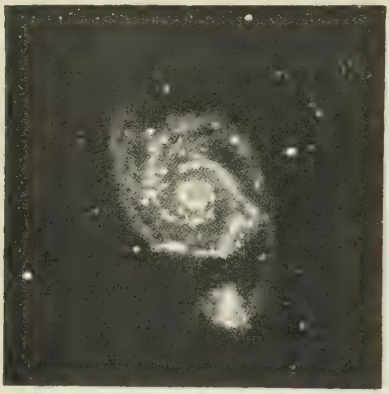
The solar system consists of the sun, about which revolve the planets with their attendant satellites, and a class of irregular bodies—comets and meteors—with somewhat different movements.

In outward succession the chief planets are Mercury, Venus, the Earth, Mars; minor planets, Jupiter, Saturn, Uranus, and Neptune. The members of the system are regulated by two natural laws, the first being that *a moving body, if not interfered with, will move in a straight line*, the second being the *law of gravitation*. The balancing of its natural tendency to move in a straight line against the gravitational pull results in the motion of the earth about the sun in a nearly circular path (really an ellipse, with the sun at one of the foci). This law is all-pervading; the sun attracts the earth, and the earth attracts the sun; the mass of the sun, however, being much greater, the earth is pulled out of its course. Similarly, all the planets rotate about the sun in elliptical paths lying nearly in the same plane. Gravitation also causes satellites to revolve about planets, and planets to affect each other's motions.

Far beyond the limits of the solar system lie the nebulæ and fixed stars, the light from the nearest of which requires three years to reach the earth. Perhaps the most wonderful objects in the heavens are the **nebulæ,** for in many cases they appear to be undergoing transformations which will result in the formation of solar systems much greater than our own.

Nearly all astronomers agree that the solar system was evolved in some way from a nebula, but variations of opinion are expressed upon the constitution of the nebula and the method of evolution. Some nebulæ appear to be indefinite luminous patches of incandescent gas; others, however, probably consist of solid and gaseous particles having

a definite arrangement. By far the most prevalent form is that of a flattened spiral in which two coiled arms may be seen (Fig. 1), implying that the spirals are due to a combined outward and rotatory movement, but that the inner parts have been coiled up tightly by faster rotation than the outer parts. A central sun is in process of formation, and nebulous knots in the arms may give birth to planets.



W. E. Wilson.

FIG. 1.—THE GREAT SPIRAL NEBULA.
Near the end star in the tail of the Great Bear.

Laplace's nebular theory was until recent years supported by most students. Briefly stated, it assumes that a *vast spheroid of gas*, extending beyond the limits of the outermost planet, was rotating in the direction of the present system. Loss of heat by radiation resulted in contraction, leading to increased rotation. At a certain stage the central portions, continuing to shrink, would draw away from the equatorial portions, which would be left as a ring rotating about the central body. Additional inner rings to the number of the present planets would be similarly formed. As the rings cooled, they parted at their weakest points and collected into planetary spheroids still hot and gaseous. A similar process separated the moons from the planets.

Dr. Roberts.

FIG. 2.—THE SPIRAL NEBULA IN CETUS VIEWED EDGEWISE.

Another hypothesis assumes that the nebula was a *swarm of meteorites, moving in different directions* with prodigious velocity, and generating great heat by frequent collisions. Professor Darwin has shown that such a nebula would behave like a coarse gas.

Professor Jeans suggests that a spherical nebula *contracts in cooling to a pear-shape ;* the swollen part is then thrown off, but rotates independently within a distance influenced by the parent mass. The process recurs in the case of the planets and their satellites.

Professor Chamberlin advocates the **planetesimal hypothesis**. In this the constituents of the nebula may be molecules or small masses of any kind—planetesimals—*revolving in the same direction* about a common centre, as are the planets to-day. Evolution consisted in the aggregation of the planetesimals into planets and satellites. The spiral nebula is the typical form, the knots in the arms being the nuclei about which the planetesimals gathered to form future planets.

The heat of the earth was acquired chiefly from compression and condensation, but also from the infall of planetesimals and molecular rearrangement, and must therefore have been highest at the centre.

The Sun.—Although there are bigger stars, or suns, in the universe, the sun assumes for us a tremendous importance by reason of its proximity. Upon its surface may be seen dark objects of enormous size, called 'sunspots,' which appear to be cavities filled with gases or vapours

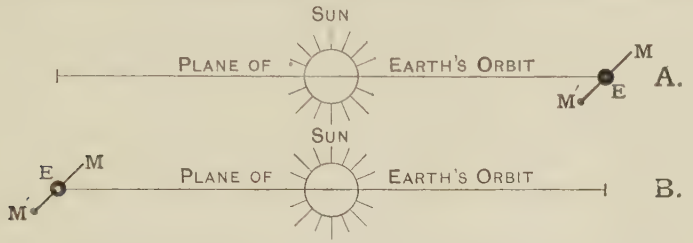


FIG. 3.—DIAGRAM TO SHOW THE TILTING OF THE MOON'S ORBIT WITH RESPECT TO THAT OF THE EARTH.

in a state of violent motion, and at a lower temperature than the neighbouring areas. From observation of the sunspots, the time of the sun's rotation is estimated at 25 days 5 hours. By means of the spectroscope (an instrument for detecting the luminous vapours of chemical elements) the sun is known to consist of at least thirty-five elements common to the earth. The sun is surrounded by a thin atmosphere—the 'chromosphere,' chiefly hydrogen with helium—often violently agitated above the spots.

The Moon.—The moon appears to be as large as the sun, because its average distance from the earth is only 240,000 miles, whereas that of the sun is over 92,700,000 miles. The moon's diameter is about three-elevenths that of the earth, and appears to vary very little, owing to its nearly circular orbit about the earth.

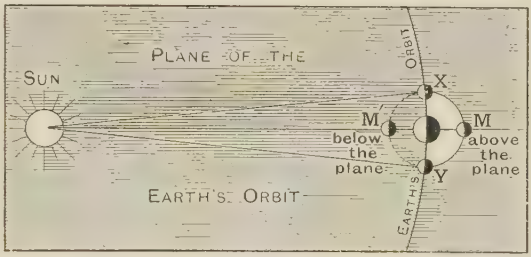


FIG. 4.—DIAGRAM ILLUSTRATING THE ILLUMINATION OF THE EARTH AND THE MOON BY THE SUN.

If we imagine our eyes to be level with the plane of the earth's orbit, we should see the moon's orbit tilted as shown in Fig. 3, where two extreme cases are given. In Fig. 4 the arrangement A is viewed from

above. When the moon is at X and Y, both moon and earth are illuminated; when at M′, the rays pass above the moon to the earth; at M, above the earth to the moon. An inhabitant of the earth also observes the moon's *phases*, from a slender crescent to a fully developed orb. At M′, the face turned to us is in shadow, but becomes partly (half at X), and then fully, illuminated as it makes a half-circle about the earth to M. Another half-circle carries it through the same phases (half at Y) in reverse order. It sometimes happens that, owing to the earth's movement about the sun, the line of intersection XY of the two orbits is in line with the sun. If, then, the moon happens to be at X (Fig. 5), a total eclipse of the sun will be observed; if at Y, the earth will intercept the light, and the moon will be eclipsed.

FIG. 5.—DIAGRAM SHOWING THE POSITION OF THE MOON DURING ECLIPSES.

The moon at Y should be in shadow, not illuminated as shown.

As it revolves, the moon keeps one face turned to the earth; it therefore turns upon its own axis once during each revolution (*i.e.*, every $29\frac{1}{2}$ days). Upon its surface the most striking features are the ring-like

Paris Observatory.

FIG. 6.—THE MOON, APRIL 15, 1900.

objects, called 'craters,' consisting of huge plains, often with central mountains or mountain-groups, surrounded by mighty mountain barriers. By some they are considered to be volcanic craters; others think they are due to the impact of meteoric bodies which have collided with our satellite. The moon has apparently no atmosphere, and no sign of water has been detected with certainty.

CHAPTER II.

The Earth.

THE heavenly bodies appear to revolve about the earth from east to west, because the earth rotates from west to east upon an axis the north end of which points towards the Pole Star. The earth makes one complete rotation in 23 hours 56 minutes, whilst travelling in an elliptical path about the sun at an average distance of 92,750,000 miles, making one revolution in 365 days 5 hours 49 minutes.

The Seasons.—About March 21 the sun rises due east, passes south of the zenith at noon, and sets due west. After March 21 (Vernal Equinox) it rises farther and farther north of east, and sets farther and farther north of west, until about June 21, when it begins to move back southwards, returning in September (Autumnal Equinox) to the same position as in March, whilst about December 22 it rises farthest south of east, and sets farthest south of west.

In June the sun in our latitude shines more directly than in January, and for several hours longer every day, because as the earth moves round the sun, its axis is inclined at about $66\frac{1}{2}^\circ$ to the plane of the earth's orbit; the earth thus presents the North Pole to the sun in June, and the South Pole in December. At each pole the sun is alternately above and below the horizon for six months at a time.

The earth may be divided into four parts or spheres:

1. *The Atmosphere.*
2. *The Hydrosphere.*—The oceans and all the waters upon the land.
3. *The Lithosphere.*—The solid outer parts of the earth—some lying beneath the hydrosphere, some protruding into the atmosphere.
4. *The Bathisphere* or *Centrosphere.*—The central core of the earth.

The outer parts of the earth constitute a region where there is contact and intermixture between the atmosphere, hydrosphere, and lithosphere. Water, for example, passes from the hydrosphere to the atmosphere and *vice versa;* similarly there is an exchange of gases between the lithosphere and the atmosphere.

However the earth first received its heat—whether from a nebula intensely hot in the beginning, or from one which became hot by aggregation of planetesimals—its temperature cannot be rising; nor can it be said to be cooling like a piece of hot iron, for there is sufficient radium being formed in the earth's crust to largely counterbalance loss of heat radiated into space. As a result of the cooling the lithosphere is settling down upon the contracting bathisphere, and one effect, manifested even in late geological times, is the crumpling of the lithosphere into the sharp folds of mountain chains.

The condition of the bathisphere is a subject of speculation. Some authorities think it is solid in spite of the high temperature, because of the great pressure to which it is subjected; in any case it behaves as if it were almost as rigid as steel.*

Tides.—The oceans are subject to tides, which consist of a periodic rise and fall of the water. Tides are caused by the attraction of the moon upon the sphere of sea-water, which is distorted and heaped up both upon the side facing the moon and upon that turned away from it. Thus, at any place high tide will occur twice a day—once when the moon is at its highest, and once when the moon is below the horizon, shining at its highest upon the opposite hemisphere. *If the earth alone were rotating, high tide would occur every twelve hours;* but since the moon is revolving in the same direction about the earth once a month, a morning tide one day will be fifty-two minutes later the next day, and so on. Therefore the intervals between consecutive high tides is about 12 hours 26 minutes, and the same intervals occur between two periods of low water. Thus two tidal swellings, or waves, on opposite sides, sweep continually round the earth.

The sun also produces tides, which are very faint because the sun is so far away. When sun, moon, and earth are in a line, as at new and full moon, the tides due to moon and sun combine to cause a greater rise and fall than usual—*spring tide.* When forming a right angle with the earth, the sun and moon work against one another, producing a smaller tide than usual—*neap tide.* Vagaries of the tide in landlocked seas are discussed in Chapter XIV.

Land and Sea.—There may have been a time when the lithosphere was covered by an unbroken sheet of water, but in the course of geological ages portions have been elevated into the atmosphere, whilst the waters

* Faint earth-tides have been detected lately.

have collected in the intervening depressions. The elevated tracts form continents and islands, the waters form oceans, seas, and lakes; the ratios of land to water being as 2 to 5.

In height the land averages about 2,300 feet above sea-level, although the highest mountain attains 29,000 feet. The most suitable spots for the support of a dense population are situated where earth, air, and sea are closely united. The average depth of the ocean is about 1,920 fathoms, but the greatest depths sink to some 5,000 fathoms. The sea-bed bordering the continents is, as a rule, shallow for some distance, forming a *continental shelf*, which then slopes rather steeply to some 2,000 fathoms, after which it has a gentler slope but plunges occasionally to the depths (Fig. 7).

The ocean basins and the great continental depressions appear to have been formed by subsidences of various ages, owing to the contraction of the earth's interior, which leaves the crust without support. The

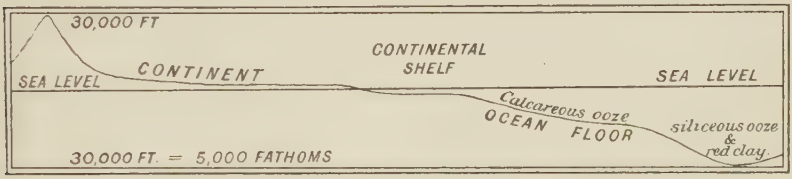


FIG. 7.—DIAGRAMMATIC PROFILE OF LAND AND SEA.
Vertical heights and depths greatly exaggerated.

waters were drawn away from the land, which appeared to rise out of the sea. At the same time contraction actually elevated and compressed the rocks along certain lines to form the great mountain-chains. Here and there also crust-blocks form high plateaux, from which the depressed areas have slid away on all sides. The continents thus consist of great earth-folds and smaller lines of mountain-folds, or blocks of land which have been left standing surrounded by areas which have been let down by gentle folds or by fractures.

The most striking feature in the distribution of land and sea is the gradual narrowing to the south of the great continents, and the narrowing to the north of the great oceans; again, at opposite poles we have the deep Arctic Sea and the high Antarctic plateau. There is, as it were, some sort of arrangement and balance in the distribution of land and sea which many have attempted to explain by assuming that the earth's crust would contract in a regular manner, following certain laws; whilst

others think that the crust beneath the ocean is heavier than that under the land which is therefore floated high above the waters.

On the bed of the ocean (Fig. 7), far away from the influence of sediment-bearing currents from land, there are certain deposits being formed, representatives of which have rarely been found amongst the rocks exposed on land. They consist of oozes formed largely of shells or tests of pteropods and foraminifera—free-swimming organisms, whose calcareous remains fall to the sea-bottom when they die—and of red clay and siliceous ooze found in the depths where pressures are so great that calcareous remains are dissolved away. A large part of the red clay consists of volcanic material and meteoric dust. Constituents of the red clay and siliceous ooze occur also in the other oozes, but are masked by the greater amount of the latter. The extreme rarity of such deposits amongst the stratified rocks has been appealed to by those who believe in the permanence of the ocean basins from the beginning of geological time.

CHAPTER III.

The Atmosphere.

THE atmosphere, or more commonly, the air, is the name applied to the mixture of gases which envelop the earth. It is elastic, compressible, and subject to gravity; hence its density, which is greatest close to the earth's surface, rapidly diminishes as the altitude increases. Thus at 3½ miles (18,480 feet) the density is only one-half, and at 7 miles one-third of that at sea-level.

In high altitudes the rarity of the air often causes mountain-sickness, and makes physical effort a great strain. The Duke of the Abruzzi has lately (1909) climbed 24,577 feet in the Himalayas, and considers that in time even Mount Everest (29,000 feet) will be ascended. From observations on meteorites which plunge into our atmosphere, it appears that even at 70 to 75 miles the density of the air is appreciable, and there is reason to believe that the atmosphere extends about 500 miles into space in an extremely attenuated condition.

The air behaves like a gas, and can be made to move from place to place. It resists a change in volume but not in shape. Since air (or any gas) enclosed in a vessel always completely fills the vessel, even if the latter is increased in size, it follows that it must exert a pressure upon the inside. This is shown by the fact that, if we keep on forcing air into a glass vessel, the latter will explode; if we exhaust the vessel, the pressure of the air outside may cause it to collapse.

The mercury barometer is devised to measure the pressure of the air at any point upon the earth's surface. It consists of a glass tube, about a yard long, closed at one end, and filled with mercury. The tube is inverted, and the open end dipped beneath the surface of some mercury in a trough. The mercury forsakes the upper end of the tube, and stands in a column about 30 inches high, which is supported by the weight of the atmosphere pressing upon the free surface of the mercury in the trough, so that the atmospheric pressure is equal to the weight of a column of mercury about 30 inches (76 centimetres) high. But since air is most dense at low elevations, the mercury does not stand so high on the top of a mountain as at its foot. Again, the pressure varies greatly from time to time at the same place, as well as between place and place.

In an aneroid barometer the pressure is measured by the deformation of the thin elastic lid of a metal box which has been exhausted of air.

Composition.—The air is a mechanical mixture of gases, the chief being nitrogen and oxygen in about the proportion of 20·96 volumes of oxygen to 79·04 of nitrogen in every 100 volumes of the mixture. The amount of oxygen falls slightly at times, especially in foggy weather, in towns, in crowded rooms, and in mines. In addition to the above, there are variable quantities of carbonic acid, water-vapour, ammonia, ozone, and nitric acid, as well as small traces of argon, neon, krypton, zenon, and helium; all being in small quantities except water-vapour, which is liable to great variations, since it depends largely upon temperature.

At any particular temperature a given volume of air can hold a certain maximum amount of water-vapour, and no more; when the air is said to be saturated with moisture at that particular temperature. The warmer the air, the higher the maximum amount it will hold. When air, saturated with moisture at, say, 20° C., is cooled to 10° C., it can no longer hold all its water-vapour, but deposits the excess as rain or mist. The temperature at which this commences to take place is called the 'dew-point.' After sunset the ground is often colder than the air above it, which is lowered in temperature and deposits its surplus water-vapour as dew. A glass tumbler full of iced water becomes covered with moisture when the air in contact with it is cooled to the dew-point. Again, when a hard frost is suddenly followed by a warm, moist wind, vapour is often condensed upon and streams down the cold surfaces of walls.

Carbonic acid gas is formed during the processes of combustion, respiration, and putrefaction; the amount in crowded rooms is greater than in the open air. Under the influence of light, the green parts of plants decompose the gas, giving off oxygen, whilst they assimilate the carbon.

In air there is always a certain amount of suspended matter, both liquid and solid. These minute particles are capable of reflecting light. The track of a beam of sunlight through a darkened room is distinctly visible (like rays streaming through the clouds), because it is reflected from the innumerable particles floating in the air. On settling, the particles form dust. In clean dry air a beam of light is invisible.

The particles are partly mineral, partly organic. Sea-spray containing sodium chloride is thrown in the air, leaving particles of salt as the water evaporates. They are never absent from the air in England. Near towns sulphates are common, through oxidation and combustion of sulphuretted compounds. Amongst organic substances are germs and organisms producing fermentation, putrefaction, and disease. Feelings of lassitude, after being in a closed room, are due rather to the organic matters breathed out by people than to diminution of oxygen or increase of carbonic acid gas in the air. The suspended particles act as innumerable points which aid the deposition of moisture; hence fogs are commoner in the dirty air of towns than in the cleaner air of the country.

Light.—If the earth had no atmosphere, only those objects upon which the sun's light fall directly would be illuminated, just as the tops of mountains outside the fully illuminated part of the moon are lit up and emerge distinctly from the inky blackness of the shadow (Fig. 6). The earth, however, and the objects upon it, as well as the clouds, reflect light and illuminate the shadows, which are rendered less intense by the atmosphere scattering the light. When thus reflected in all directions, light is said to be *diffused*. If a beam of light falls upon a mirror or polished surface, it is reflected as a beam, only to be seen from one position. When a beam passes from one medium to another—say, air to glass, or a layer of dense cold air to one warmer and lighter—it is bent out of its straight course at the boundary of the two media, but pursues a straight course in the second medium. This property is called *refraction*, and gives rise to some interesting phenomena. Thus the sun, although actually below the horizon, may appear above it, because the rays are bent as they traverse successively denser layers of the atmosphere. To an observer

at A, Fig. 8, the rays appear to come from S′, whereas they really come from S, the sun being actually below the horizon.

According to the undulatory theory, light* is due to rapid vibrations set up in an all-pervading ether, which give rise to waves travelling from the source of light at the rate of 186,000 miles per second; and when these vibrations enter the eye, they excite the sense of vision. White light is made up of waves of different lengths, which, when separated, give different colours. If a beam of sunlight is passed through a prism and allowed to fall upon a screen, it is refracted. The patch of light seen will no longer be white, but coloured like a rainbow, the colours grading imperceptibly from red, through orange, yellow, green, blue, and indigo to violet. These primary colours form what is known as the *spectrum*.

The phenomenon is known as *dispersion*. The colours of smallest wave-length (violet) have been most refracted, and those of greatest wave-length (red) least refracted. Rainbows are caused by dispersion

FIG. 8.—BENDING OF THE SUN'S RAYS OWING TO REFRACTION.

of sunlight by falling raindrops and reflection of the consequent colours to our eyes. Each person sees a different rainbow, although two observers may stand side by side. Again the sky is blue, partly because the rays of shortest wave-length are scattered by the impurities in the air and reflected to the observer, the remainder passing on as white light. (The colour of the sky is partly that of pure oxygen, which is also blue.) At sunset the light traverses a greater thickness of impure air filled with dust particles, hence the rays of short wave-length are obstructed, whilst the remainder pass on, and give rise to the yellow, red, or coppery tints of sunset.

The sunset effects of the winter and spring following the outburst of Krakatoa in 1883 were particularly striking, because of the volcanic dust suspended in the atmosphere.

* A later form is called the 'electro-magnetic theory' of light,' in which the vibrations consist in a periodic alteration of the electrical and magnetic conditions of the ether during the passage of light.

Heat.—The atmosphere is heated chiefly in two ways—by the internal heat of the earth, and by the sun's rays.

Since heat flows from places of high temperature to those of low temperature, there must be a steady flow of heat from the centre of the earth to the surface, for we find that the mean temperature of the earth increases steadily as we descend in depth, averaging about 1° C. for every 30 yards. Whereas the amount of heat thus added to the atmosphere is small but constant, that derived from the sun is great but variable in amount.

Heat from the sun is *radiant heat*, a form of energy conveyed in all directions by waves set up in the ether. The radiant heat which reaches the earth does not heat the intervening space, nor has it much effect upon a clear atmosphere. Some of it is reflected (just as light may be) by suitable objects, but a great deal is absorbed by the earth, more especially those parts which are dark.* If air contains much water-vapour or dust, the sun's rays are intercepted : thus less heat than usual reaches the earth on cloudy or hazy days, and in the late afternoon, when a great thickness of air must be traversed.

Heat is transferred from one place to another by (*a*) radiation, (*b*) conduction, and (*c*) convection.

The atmosphere is slightly heated by the *radiation* from the sun and the radiant heat reflected from the earth's surface.

In the daytime the earth is receiving much more heat than it is losing by radiation, therefore its temperature rises ; but at night its temperature falls quickly, especially if the atmosphere is clear and free from water-vapour which prevents radiation. But just as heat travels towards the handle of a metal spoon in a cup of hot tea, so the cool air *in contact with the warmed earth* is heated by *conduction* of the heat from the warm earth.

Again, it is a property of gases to expand when heated and become lighter. Thus layers of air near the earth's surface, becoming heated by conduction, expand and rise, whilst the colder and denser air above sinks to the earth, setting up *convection currents*, which are greatest during the daytime, when the earth is hot.

The temperature of the atmosphere at any place depends upon latitude, change of the seasons, the influence of oceans and winds,

* White flannels, or 'ducks,' reflect more, and absorb less, radiant heat than dark clothes.

geographical situation, and the occurrence of day and night. Generally speaking, temperatures are highest at the equator, and become progressively cooler polewards, but this simple arrangement is modified by other conditions.

Daily Temperature Range.—In the North Atlantic the *Challenger* Expedition found that where the daily temperature range—*i.e.*, the difference between the highest and lowest temperature—of the water is less than 1·8° F., that of the air above is only 5·78° F., since the comparative coolness of the sea by day and its warmth by night prevent any greater extremes. Near land, however, the temperature range rises to 7·9° F., because the sun's rays, being concentrated upon a shallow depth, raise the temperature of the water more quickly.

The daily range on land is much greater than at sea, and increases, as a rule, as distance from the sea increases and latitude diminishes. At London the range is greater than at Gibraltar, but much less than at Moscow. Above all, the range depends upon the dryness of the atmosphere, which facilitates radiation. In the arid plain of the Indus (Pachbudra) in summer it rises to 74·3° F.; in California to 54° F., whilst in the centre and South of England it touches 36° F., and only 18° F. in the islands to the North.

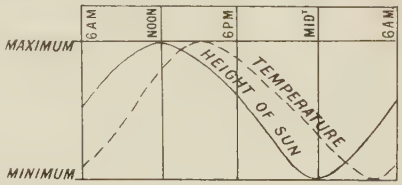


FIG. 9.—DIAGRAM TO SHOW HOW DAILY MAXIMUM AND MINIMUM TEMPERATURES COME LATER THAN THE TIMES OF MAXIMUM AND MINIMUM HEIGHT OF THE SUN.

Daily maximum temperature, both on land and sea, occurs not at noon, when the sun is highest, but some time afterwards. At Kew and at Rothesay it is at 3 p.m., but near the sea, at high altitudes, and in the tropics, it is earlier—at Aberdeen at 2 p.m., and at Batavia at 1.20 p.m. In winter the daily maximum occurs about one hour earlier than in summer, because the sun quickly loses its power for heating. Similarly the coldest part of the night is not at midnight, but from 5 to 6 a.m.

Annual Temperature Range.—Near the equator changes of the seasons do not cause much difference between the winter and summer temperature over the sea, the annual range—*i.e.*, the difference between the average temperature of the hottest and coolest months—being exceedingly small. In higher latitudes, however, the annual range is

greater: the average temperature of Iceland for July is about 50° F., but in January it falls to 30° F. At the Cape of Good Hope the range is about the same (Figs. 10 and 11).

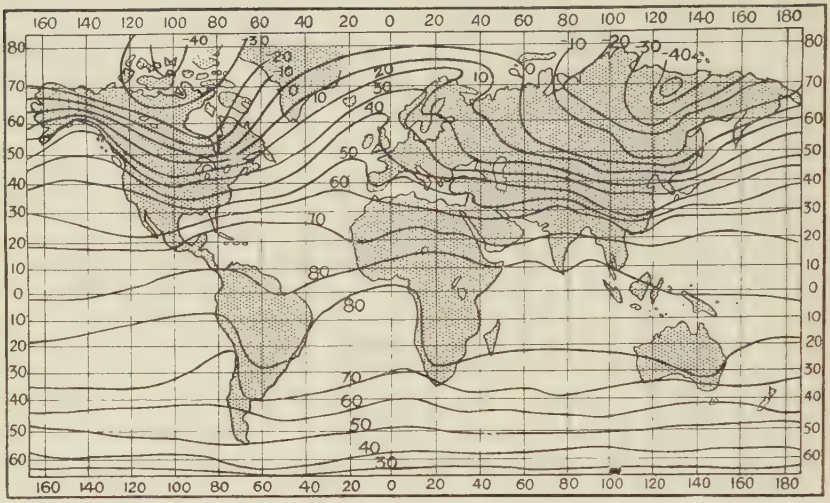


FIG. 10.—ISOTHERMALS OF THE SURFACE OF THE GLOBE FOR JANUARY.

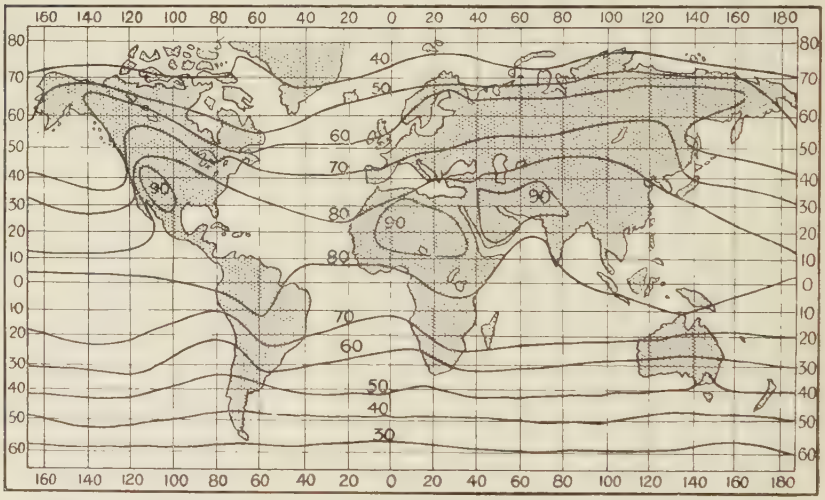


FIG. 11.—ISOTHERMALS OF THE SURFACE OF THE GLOBE FOR JULY.

Temperatures in degrees Fahrenheit.

The ocean warms very slowly, and cools almost equally slowly, therefore the daily and annual ranges in temperature are much less than on land, which warms quickly and loses heat equally quickly. Whereas most

of the sun's heat upon land is absorbed at the surface, and the daily rise in temperature is unnoticeable at a depth of 4 feet, it penetrates at least 500 feet into water, and is diffused throughout a great volume. *The small annual range in temperature on the sea affects the temperature of coast-lines and islands within reach of the sea-breezes.* Absorbing heat from the waters, the winds blow inland and temper the rigours of winter, but in summer the sea-breezes are cool and refreshing. Inland, in fairly high latitudes, far away from the sea, and where the atmosphere is dry, the cumulative effects of long cold nights and short hours of sunlight in winter, and short nights and long dry days in summer, give rise to great annual extremes.

In North Spain, for example, the July temperature is 70° F., and the January temperature 50° F., a range of 20° F. (Figs. 10 and 11); but in North Siberia, near the middle course of the Lena, it ranges between 60° F. for July and −60° F. for January, or 120° F. altogether.

The highest temperature occurs later than the time of the longest days, and the lowest temperature later than midwinter—a lagging effect similar to that shown by the daily maxima and minima.

Ocean Drifts and Currents.—Discussion of the circulation of the oceanic waters is deferred to Chapter XIV.; it will here be sufficient to point out its effect upon temperature.

The great whirls north and south of the equator carry heated waters from the latter, and wash the western shores of the great continents in higher latitudes. Winds accompanying these whirls are warmed by conduction, blow inland, and temper the climate of the countries in their path. The great gulf of warmth in January, which in the North-East Atlantic (p. 152) extends quite across the Arctic Circle, embracing the British and Faroe Islands, is due to the warm breezes blowing off the North Atlantic Drift. On the other hand, the cold Labrador Current, creeping down the east coast of North America, renders the temperature of districts in the same latitude as the British Isles more like that of Iceland or South Greenland.

Winds and Moisture.—As shown above, the temperature of parts of the earth's surface is modified by the winds, some of which transfer heat from the equator to cooler zones, whereas others carry cold air towards the equatorial regions, where it is warmed. *The winds, being carriers of moisture, have a great influence upon climate,* for moisture-laden air becomes warmed by the sun's rays, and prevents radiation and great

daily extremes of temperature. Again, if such air is cooled, and moisture precipitated as rain or snow, there is a liberation of heat equal in amount to that which was absorbed during the process of evaporation ; thus the fall in temperature is checked. Moisture-bearing winds are responsible for the equable temperatures of Ireland and Cornwall.

Great inland plains swept only by winds which have been dried, frequently suffer extremes. Even in the Sahara—where the average annual temperature is high and the annual range small—the daily temperature range is great, causing rocks to fall to pieces by alternate expansion and contraction by day and night (p. 65).

Geographical Situation.—At great heights the atmosphere is rare and clear, and holds little moisture, therefore radiation is easy, and extremes to be expected. *Elevation counteracts effects due to latitude ;* even at the equator there is perpetual snow at an elevation of some 18,000 feet. In general, valleys are warmer than hill-tops, and the sides of hills facing the sun warmer and more suitable for cultivation than those turned away from it.

Isotherms.—Isotherms are lines connecting places at which the temperatures are alike at any time or during any period. Study of the isothermal charts of the world for July (average temperatures for the month) and January (Figs. 10 and 11) proves that temperature differences agree with latitude only in the broadest sense, being also controlled by winds, pressure, rainfall, ocean currents, and elevations of the land.

Circulation of the Air.

Pressure.—Since the barometer is never steady for any length of time, the pressure of the atmosphere must be constantly changing. Some changes are periodical, and depend upon the time of day or year ; others are irregular, and responsible for what we call ' weather.' Changes of pressure mainly depend upon changes of temperature, which, as we have seen, are numerous, and due to many causes.

If any place is heated more than those around it, the air above it—heated by conduction—expands, and the higher strata flow away from it over the surrounding less heated area. The first effect of the expansion is a mechanical increase of pressure,* which continues until the higher layers of the atmosphere are raised to such a height that they, so to speak, slide off and flow away on all sides. An ascending column of air

* Bicycle tyres, heated by the sun, often explode through a similar rise in pressure.

is then formed, which produces an indraught from below, and finally lowers the pressure.

Winds.—Wind is air thus set in motion. Over a relatively cold area the air will contract and lower the pressure, so that the upper strata will flow in towards it from neighbouring areas. *Over tracts from which air flows, the pressure is reduced; over those to which it flows, the pressure is raised.*

In the equatorial region the expansion of the atmosphere is greatest; therefore there is a tendency for an undercurrent of air to travel towards, and an upper current to flow away from, the equator. The heating is most violent over the land areas; over the sea it is less violent, but more constant. The under-currents blowing to the equator are known as the 'Trade Winds'; the upper currents, blowing from the equator, and gradually descending to sea-level, as the 'Anti-trades.'

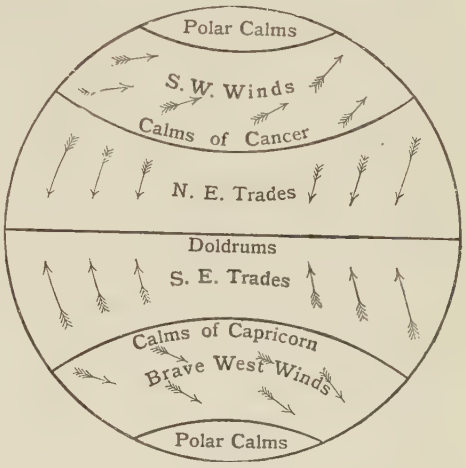


FIG. 12.—CIRCULATION OF WINDS (Diagrammatic).

Instead of blowing from north and south to the equator, the Trades blow from north-east and south-east, and the Anti-trades from south-west and north-west respectively. This is owing to the rotation of the earth, which causes winds blowing to the equator to be deflected to the west, and those away from it to the east; *hence winds are deflected to the right in the Northern Hemisphere, and to the left in the Southern Hemisphere.* The zones of Trade Winds shift north and south with the apparent movement of the sun across the equator, and the Anti-trades follow suit.

On Teneriffe, in summer, there are south-west winds at the summit of the Peak. With autumn the sun moves southwards, and the Trade Winds follow. The south-west Anti-trades then creep slowly down the mountain-side, until they envelop the island from base to summit.

The Anti-trades are partly drawn back into the Trade Wind circulation, and partly flow towards the poles, where they form variable winds

chiefly regulated by the contrasts in temperature between continents and oceans. They form a whirl of air round both poles.

Thus, in each hemisphere there are four belts of winds :

A. The Doldrums, or equatorial calm belt, with variable winds, close to the equator.

B. The Trade Winds.

C. The belt in Trades in summer, Anti-trades in winter (Horse Latitudes, or Calms of Cancer and Capricorn).

D. The belt of variable winds, mostly westerlies, on the polar side of the Trades.

The relations between atmospheric temperature and pressure and the resulting winds are given below.

The barometer falls :*

1. When the lower strata of air are heated, causing an updraught, as already explained, for by this means the pressure is reduced.

2. When the air is damp, for damp air is lighter than dry air.

3. When vapour is condensed into clouds, rain, or snow. This action heats the air, and thus increases the force of the ascending column. After rain has fallen the barometer may rise again.

4. When the air is in motion, for gases in motion exert much less pressure on the walls of their containing channels than when at rest.

Conversely, the barometer rises :

1. When the air is very cold, for then the lower strata are denser and more contracted than when it is warm, and air flows in above to fill up the deficiency.

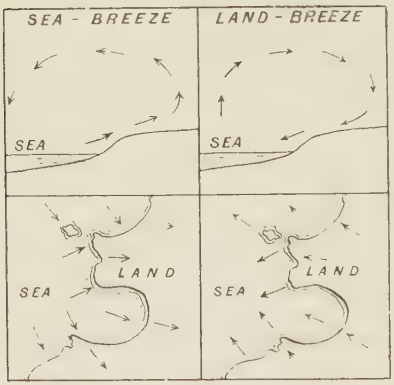


FIG. 13.—SEA-BREEZE AND LAND-BREEZE.

The upper figures in section ; the lower figures in plan.

2. When the air is dry, for then it is denser than when it is moist.

3. When the air flows in towards any region, and a corresponding outflow does not exist.

The above principles explain why the barometer is relatively high in regions which are extremely cold, and relatively low in those which are extremely hot; the equatorial belt, for example, is one of low pressure, towards which the Trades pour water-vapour.

Periodical Winds. — On the sea-coast there are often local movements of air due to *daily* temperature changes. During the day the land becomes heated, the warmed air in contact with it ascends and passes out to sea, where it is chilled again, whilst a cool sea-breeze blows inland. At night the reverse happens :

* 'The Admiralty Manual of Scientific Enquiry,' p. 162.

the air over the land is chilled, and, becoming more dense, flows out to sea as a land-breeze ; thus a local circulation is set up. The effects of these breezes can only be observed on calm days, and do not extend far inland or out to sea. Sea-breezes, as above stated, moderate the daily maximum temperature, and cause it to occur earlier than it would do normally.

On land the wind's velocity and the height of the barometer are increased daily—when the temperature is above the mean for the day—by heating of the ground and the ascensional movement of the air. After midday winds may spring up only to die away at nightfall, a fact well recognized by aviators and yachtsmen.

The furious blasts of cold air which sweep down many mountain valleys nightly are due to the air of the mountain-side becoming so chilled that it sinks and displaces the warmer air of the valleys. In the daytime breezes blowing out of the valleys are less severe than those of the evening, because they are not so concentrated, and have to overcome gravity.

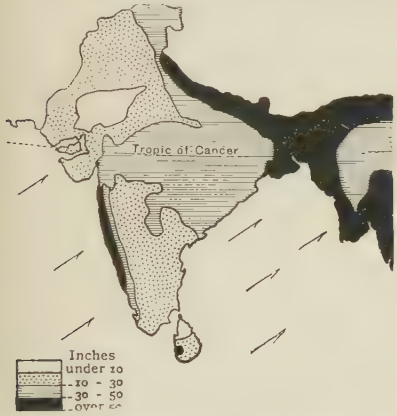


FIG. 14.—MONSOON CONDITIONS IN INDIA, MAY TO OCTOBER.

Rainfall in inches.

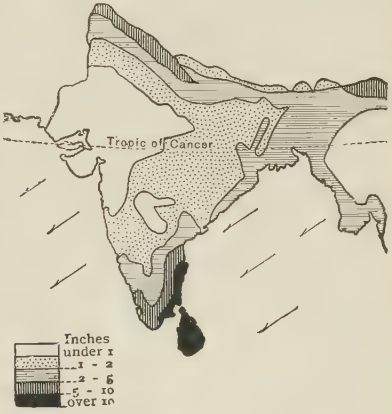


FIG. 15.—MONSOON CONDITIONS IN INDIA, NOVEMBER TO APRIL.

Rainfall in inches.

Certain winds are caused by temperature changes at definite *seasonal* intervals.

North and south movement of the Trade Winds, with the seasons, gives rise to winds in places where calms or light winds prevailed before ; thus, the equatorial belt and the Horse Latitudes are periodically invaded by the Trades.

Heating and cooling of the land in summer and winter gives rise to *Monsoon* winds, and since the seasonal range in temperature is greatest

north and south of the tropics, periodic winds are there the most pronounced. Between May and October the heat of Central Asia causes an updraught, which draws in the cooler winds from the Indian and Pacific Oceans; but between November and April the process is reversed through excessive cooling of the land—the pressure rises, and winds flow out to sea. The summer Monsoons of India, blowing from the south-west, are laden with moisture; the so-called winter Monsoons—really he North-East Trades—are drier and bring lighter rains (Fig. 15).

Monsoon conditions are well developed in Australia, for in summer the south-east Trades bring rains to the north and east coasts; in winter they blow off the land. In cold, snow-covered regions—since the sea, even in summer, is warmer than the snow—the prevailing winds tend to blow seawards. This is the case in Greenland; and in the Antarctic Sir E. Shackleton met a steady wind from the south during his recent expedition.

Isobars.—Winds flowing from places of high to places of low barometric pressure are said to follow the fall in the *barometric gradient*. This gradient can be best seen by study of a chart upon which 'isobars' are inserted. Isobars are lines drawn through places at which the barometer stands at the same height, or places having equal barometric pressure. Speaking generally, in both hemispheres (Figs. 16 and 17) the barometer is highest in winter over the land, and lowest over the sea, which is then warmer than the land. In summer the positions are reversed, but it must be remembered that the northern summer corresponds with the southern winter.

Winds blow in the direction of the fall in the barometric heights, but, owing to the earth's rotation, they cut the isobars at an acute angle. The greater the difference in pressure between two spots, the steeper the gradient, the closer the isobars, and the stronger the winds.

Cyclones and Anti-Cyclones.—Suppose local heating of air sets up an ascending current, and causes the barometer (after first rising) to fall, then winds following the barometric gradient sweep *inwards* from all sides to restore equilibrium. Such an area is called a *depression*. But since winds in the Northern Hemisphere are deflected to the right, they, in this case, set up a whirl revolving in an anti-clockwise direction. In the Southern Hemisphere the direction is clockwise. These whirls, or 'cyclones,' are set up in the main systems of winds, and are carried along with them.

Contrariwise, in each hemisphere winds move about centres of high barometric pressure in an exactly opposite direction—*i.e.*, *outwards*—

clockwise in the Northern Hemisphere, and anti-clockwise in the Southern. The winds of a cyclone are much stronger than those of an anti-cyclone, chiefly because, blowing inwards, they are concentrated on a small area.

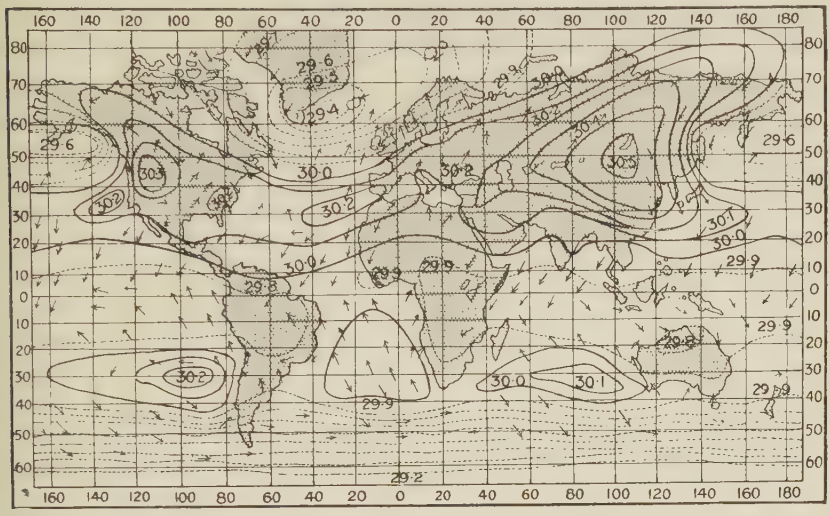


FIG. 16.—ISOBARS OF THE GLOBE, AND PREVAILING WINDS FOR JANUARY.

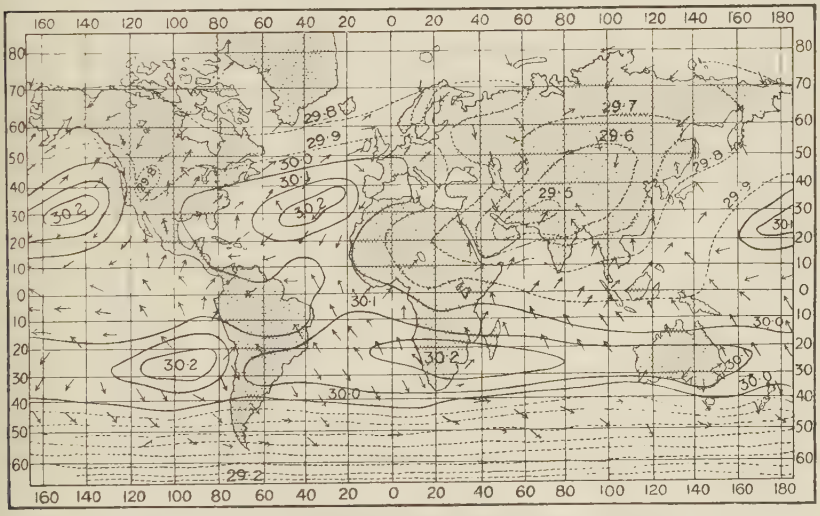


FIG. 17.—ISOBARS OF THE GLOBE, AND PREVAILING WINDS FOR JULY.
Barometric pressures in inches of mercury.

Local disturbances in the prevailing south-west winds of the British Isles give rise to cyclones and anti-cyclones, which travel onwards, generally in the same direction, and furnish types common to all

temperate latitudes. Numerous stations situated in all parts of the British Isles make daily records of temperature, pressure, humidity of the air, rainfall, wind velocity, and state of the sea, which they forward to the Meteorological Office. Records are also despatched from Iceland, Valencia, the Azores, Faroes, and liners upon the high seas. The results, plotted upon maps (weather-charts) form the basis of weather forecasts for the next day.

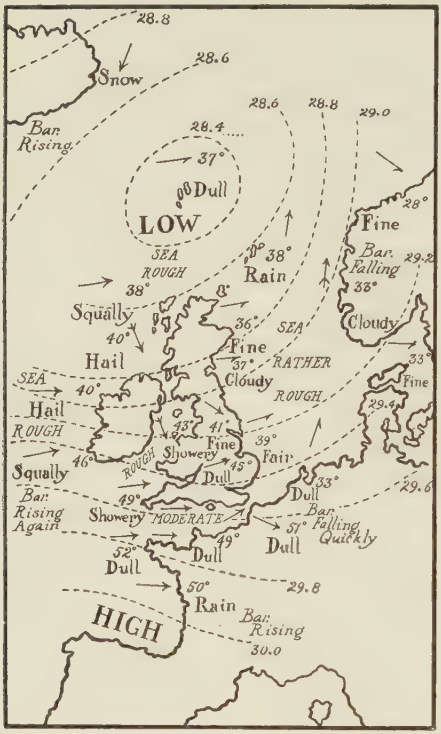


FIG. 18.—WEATHER-CHART (January 13, 1909) SHOWING A TYPICAL CYCLONE.

The dotted lines are 'isobars,' the heights of the barometer being given at the ends, thus ----- 30. The shade temperature is given in figures. Light wind, —→ ; fresh or strong, —→ ; a gale, →—→ ; calm, ⊙.

Two charts have been selected to show a typical bad-weather cyclone (Fig. 18) and a typical fair-weather anti-cyclone (Fig. 19). In the first case strong winds cross the isobars obliquely in an anti-clockwise direction; in the second case, light winds blow obliquely outwards in a clockwise direction. These charts also illustrate a principle known as the **law of Buys-Ballot**: *Stand with your back to the wind, and the barometer will be lower on your left-hand side than on your right.* This is useful knowledge, but the direction of the wind alone is an insufficient guide to forecasting weather; we also want the shape of the low or high-pressure area, its gradients, the rate of increase or decrease in intensity, and the direction and speed at which it is moving.

Cyclones move quickly, and follow one another in series, causing unsettled weather with a jumpy barometer, whereas anti-cyclones move slowly, and usually cover larger areas. Once established, an anti-cyclone is broken up with difficulty; the air is dry, and driest when the barometer is highest, but the latter sometimes falls to a low level, which would be accompanied by rains under cyclonic conditions. As a cyclonic

centre journeys forward, any particular place over which it passes will experience a change in wind. In Fig. 20 the winds at A are at first south and south-east, but after the centre has passed, they veer round to north and north-west.

Hurricanes and typhoons are violent cyclones of steep barometric gradient (the fall is sometimes 2 inches) arising in the warm belts near the equator. They often move in curved paths, and appear to originate upon the sea, being most frequent in the West Indies, near Mauritius, in the Bay of Bengal, and the China Seas. Travelling at a speed approaching 300 miles a day, the violence of the wind is almost incredible ; but in the centre of the whirl, strangely enough, the air is calm, the sky clear. The danger to ships is the sudden shift in the winds after the centre has passed. Great destruction is wrought when they pass over oceanic islands, for the great ocean waves produced frequently devastate low-lying districts. In October, 1876, 100,000 people thus lost their lives upon the Ganges coast.

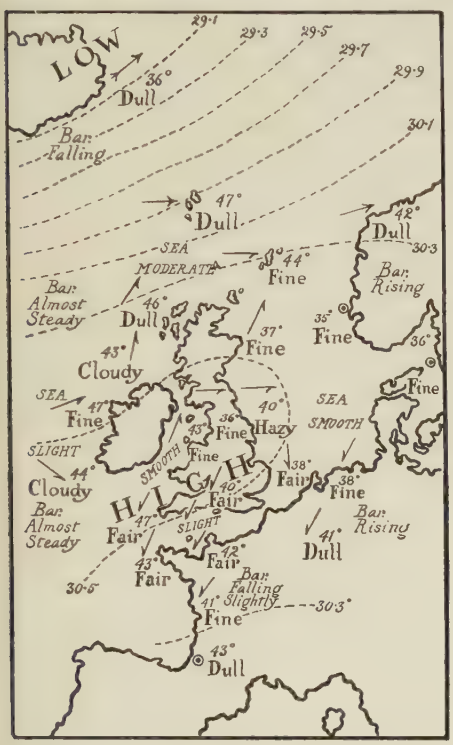


FIG. 19.—WEATHER-CHART (January 20, 1909) SHOWING A TYPICAL ANTI-CYCLONE.

Explanation of signs, etc., as in Fig. 18.

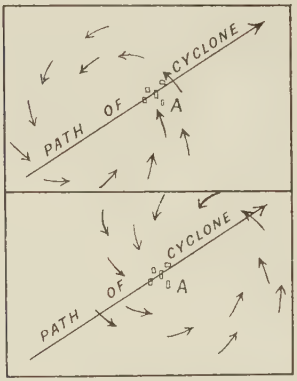


FIG. 20.—DIAGRAM SHOWING THE CHANGE IN THE WINDS CAUSED BY THE PASSAGE OF A CYCLONE.

Tornadoes in hot moist districts are small, violent, and local storms, consisting of whirling masses of air moving at a great pace, whose approach is usually heralded by a funnel-shaped cloud. Tornadoes are frightfully destructive, because the air in the centre is rising rapidly. When passing over water, one or more waterspouts may be formed.

Thirty or forty cyclones yearly approach Britain from the west ; the storm paths for the most part being over the sea, for the land impedes the winds by friction.

British weather is largely dependent upon the above-mentioned centre of disturbance, together with a second, east and south-east of Britain—the Monsoon area of Europe-Asia—and a third off the Azores, a centre of high pressure. Slight movements of these centres are continually causing changes in the weather.

Clouds.—As already explained, air can only hold a certain maximum amount of water-vapour at any given temperature, and is then said to be *saturated*. If cooled below the temperature of saturation (by radiation, by contact with cold air or earth, or by rising into higher regions), some of the vapour is condensed to minute drops of water, which form cloud. A low-level mist is just as wetting and as dense as a cloud from which rain is not actually falling. The most important forms assumed by condensed water-vapour are : 1, Fogs and mists ; 2, Clouds.

1. When the temperature of the air near the ground falls below the dew-point, the air immediately above the ground becomes filled with minute drops of water, whose condensation is aided by floating impurities. The dry yellow fogs of cities are full of particles of smoke and dust, whereas the whiter and wetter country fogs consist more exclusively of droplets of water. Evening mists in the valleys rise and dissolve when the morning sun warms the air so that it can hold more water-vapour ; but a thick fog or mist is dispersed with difficulty, because the upper layers trap the rays and prevent them from warming the ground.

If bodies of cool air slowly mingle with warm air near the saturation-point, fogs may persist for days, in spite of brilliant sunshine above ; the cool air chills the upper layers as fast as they are warmed. On the Newfoundland Banks, where the Gulf Stream and the cold Labrador Current are side by side, fogs are frequent when the winds of one region pass over to the other.

2. The *cumulus* is the primary and most typical cloud. Water-vapour, being lighter than air, rises more or less rapidly ; therefore on a warm calm day moisture-laden air *ascends, partly by expansion, and partly because of the contained vapour*, and soon reaches an elevation at which the temperature is low enough to condense the vapour. The rise continues until the heat liberated upon condensation is expended, when the top of the cloud which has been formed falls back upon itself in globular masses like those emitted from the funnel of a locomotive. The surface of the heated air tends to rise in columns, the heads of which form the similar-sized masses of cumulus cloud so commonly seen floating across the sky upon a fine summer's day. Cumulus clouds in a series

usually have flat bases all at about one level, for the stratum of air just below the clouds is at saturation-point. Should the air become chilled from above, the cumuli will be added to below, and may unite to form a solid bank of cloud.

Clouds are suspended in the air by the friction of the little globules of water, which renders them unable to fall easily; those which do slowly fall are evaporated in the warm air, whilst others are condensed above.

If nearly saturated air is in motion, its water-vapour may become streaked out into a stratum and then condensed, when the cloud-form

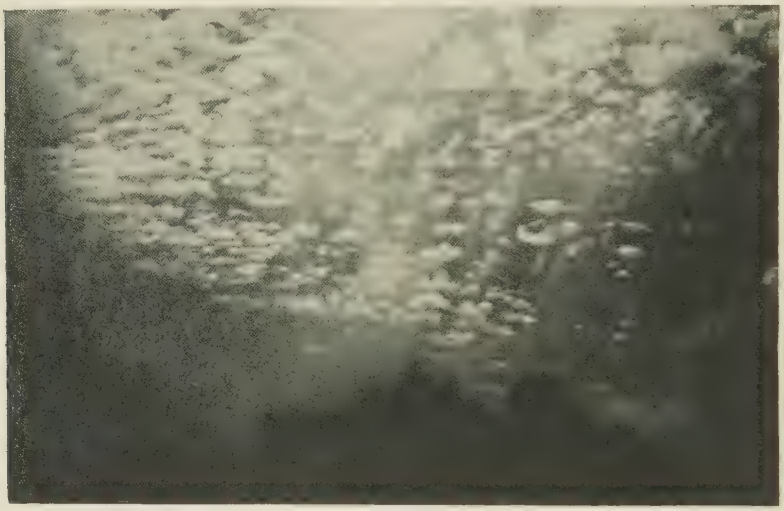
Prof. Lockyer.

FIG. 21.—CUMULUS CLOUDS.

assumed will be the *stratus*—a long horizontal cloud with a flat surface. The air about the top of a cumulus is often moving faster than that below, which is heavier, and has to contend with the friction with the earth, the result being that the upper part of the cloud shears over into a slanting position, and becomes flattened; but its cumulus character is never lost. Such a cloud is a *cumulo-stratus*. Again, movement of the upper air over the lower may throw the latter's surface into waves, like those produced by wind or water. Condensation at the crests of the waves will produce clouds corresponding to long water-waves or

those of a choppy sea. The first will lie in parallel bars; the second form the popular '*mackerel sky*,' which, however, may be partly caused by rapid expansion from below.

All these clouds are formed in the lower layers of the atmosphere; cumulus at an average height of from 4,000 to 10,000 feet, and stratus between 3,000 to 20,000 feet. There is a drier atmosphere above, whose vapour only becomes visible at heights of 25,000 to 30,000 feet as the *cirrus* cloud, with its variations *cirro-cumulus* and *cirro-stratus*. Their formation is similar to those above described, but the clouds are usually formed of minute crystals of ice instead of drops of water.



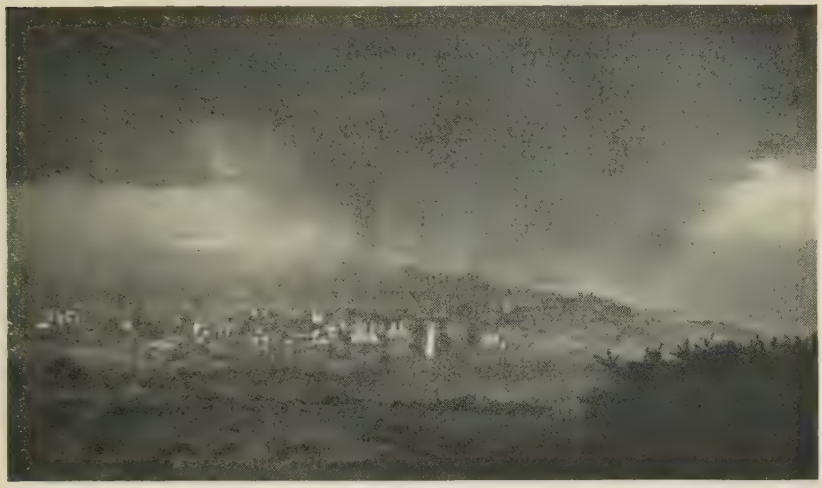
Prof. Lockyer.

FIG. 22.—CIRRO-STRATUS CLOUDS.

Rain.—By contact with each other the small globules of water in a cloud may grow in size until they become too heavy to be supported, and fall as rain, when the cloud is called a *nimbus* (Fig. 24). Most rain falls from cumulus clouds, from the stratiform clouds of cyclones, and from the moist winds which blow from water over land. Quick condensation and packing of the clouds seem to favour the production of rain. Mountains near the sea are liable to be rained upon, because the moist warm winds blowing from the water strike against the mountain-side and become chilled; moreover, in rising to traverse the mountain passes, it is still further chilled, both because it expands on relief of pressure, and because it reaches cooler layers of air. Thus, rain falls

upon the seaward slopes to such an extent that, if the mountain-range be great enough, the winds, warmed during their descent upon the inland flanks of the range, will precipitate little or no rain. This dryness to the leeward of mountains has been termed their 'rain-shadow.' Desert conditions prevail where the annual rainfall is 10 inches or less—in other words, where the rain-shadow is dense. Winds blowing from continents to the sea usually precipitate very little rain. In India the greatest fall occurs during the summer Monsoons (Fig. 14).

Fig. 23.—Effect of Vertical Relief on Rainfall.



Judges, Ltd., Hastings.

Fig. 24.—A Rain-Cloud (Nimbus) over Eastbourne.

Snow.—When saturated air is chilled below freezing-point, snow is precipitated. Snowflakes are small aggregates of ice crystals, each crystal having hexagonal symmetry. Professor Tyndall, when in the Alps, once noticed snowflakes falling through the still air, each flake being a beautiful six-rayed snow crystal. Water-vapour can pass directly from the air to form snow—*i.e.*, ice—just as easily as ice can disappear as water-vapour by evaporation. The same storm may shed snow on the highlands and rain on the lowlands, the snow melting as

it falls. When half melted it forms *sleet*. If, however, ascending air currents of lofty thunderstorms carry raindrops so far upward that they are frozen, they then descend as balls of ice, or *hail*.

FIG. 25.—MEAN ANNUAL RAINFALL OF EUROPE.

Rainfall in inches.

Speaking roughly, snow falls only on high ground between 30° N. and S. latitude; beyond these limits it may fall at sea-level. The snow-line, which is at 18,000 to 20,000 feet in the tropics, descends to sea-level about 60° N. and S. latitude.

There is a close connection between geographical situation and rainfall. The wettest parts of South Europe are the high lands near the sea, where south-west winds are prevalent. The Carpathians are in the shadow of the Alps (Fig. 25).

British cyclones from the south-west bring most of the rain for the year. When a cyclone passes, there is a definite relation between the different portions of the cyclone and the nature of the cloud. In front variations of the cirrus cloud appear, followed by the nimbus or complex mass of cloud, which discharges the rain chiefly from the south-eastern parts of the cyclone. In the centre there are alternate patches of cloud and blue sky. In the rear cumulus is abundant, especially in the south, with stratus in the north. The whole is followed by cirrus.

CHAPTER IV.

Climate and Geographical Distribution.

THE climate of a country is the average of its weather, including daily and weekly variations in temperature, pressure, wind, and rainfall. A country's climate may, on the average, be moderate, whereas the climates of two different localities in that country may be extremes.

Climatic Belts.—A simple classification, based upon temperature, is that dividing the earth's surface into Torrid, Temperate, and Frigid

zones; but, since the earth's rotation has so much influence upon the original circulation set up by temperature changes, a better plan is to base climatic zones upon the wind and pressure belts (p. 18) typically developed over the great oceans.

The *Equatorial belt* has a sultry, humid atmosphere, with constant and copious rains, and strongly marked diurnal changes.

In the *Trade Wind belts* the air is dry, the rainfall light, and the winds steady.

The *Horse Latitudes* have light variable winds and frequent calms. In the higher latitudes cyclones are frequent, especially in winter.

The influence of land upon the winds, pressure, and rainfall has been discussed above; the high relief of some parts is accountable for deserts screened from rain-bearing winds. Absence of high mountains near the western margin of Europe allows the moisture of the Atlantic to penetrate far inland (Fig. 25). In the same latitude climates vary according to the height of the district above sea-level. The summits of high mountains have a polar and arid climate, with great extremes; on their sides, however, the daily range is minimized by ascending currents, which discharge moisture and warm the air, and descending currents, which cool the lower slopes. Rainfall and temperature changes are extremely rapid as one ascends, in contrast to the uniformity prevailing over large areas on the plains. On the whole, mountain temperatures are low, and there is more rain than on the plains, where the streams from the mountains may wither away if the climate is dry. Opposite slopes often have different climates; the eastern slope of the Andes receives much rain; but the western slope has a dry climate; thus sunlight and rain may raise the zones of vegetation upon the favoured mountain-side.

Distribution of Plants and Animals.—The distribution of vegetation and animals at the present day depends upon climate, geographical situation, and earlier geological history. Similar plants tend to occur in similar areas; wood and moorland, heath, bog, and sea-shore have each their peculiar flora. The prickly cactus of one arid district is represented by almost similar prickly plants in another desert area. Similarly, two districts far apart, but alike in character, may possess characteristic faunas—*e.g.*, the forest monkeys—differing only in the individuals. The similarity is due to the *environment* or *surroundings*, which permit of certain attributes in the inhabitants of the district.

The *lands* are roughly belted with zones of vegetation no less marked

than the climatic belts. Under the heavy rains at the equator there are dense and mighty *forests*, surrounded, where the rainfall is slightly less, by *grassland* and *scrub*, or open park-like land suitable for cultivation. The Trade Wind belts are often *deserts—e.g.*, California and Chile, the Sahara, Arabia, and Central Australia. In Asia deserts are due to 'monsoon' conditions. North and south of the deserts are grasslands, such as the *prairies*, *plains*, and *steppes* of America, Europe, and Asia, and the plains of South America and New Zealand—often converted into splendid arable land. In the northern hemisphere these are followed by the *temperate forest regions* of Canada, Norway, Russia, and Siberia, and then on both sides of the Arctic Circle come the *tundras* of North America, Greenland, Iceland, and Siberia.

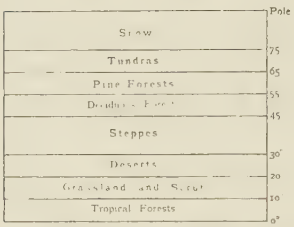


FIG. 26.—LATITUDINAL ZONES OF VEGETATION ON WESTERN SIDES OF CONTINENTS.

The *shore-line* being the meeting-place of air, water, and land, conditions are continually changing, and the forms of life are equally varied.

In the *open sea* the drifting organisms (plankton) and the free-swimming organisms (nekton) vary from algæ and small foraminifera to whales. Certain types are widely distributed; others are localized by temperature, depth, or saltness of the water.

The *deep sea* has its own peculiar types, amongst which are fishes adapted to live under great cold and pressure. The darkness accounts for the almost complete absence of plants.

In the *fresh waters* also, amongst both animals and plants, there are littoral forms, surface forms, and deep-water forms.

The factors influencing distribution are—*

1. *The physical peculiarities of the region and the constitutions of the organisms.*

2. *The original home of the stock and means of dispersion in each case.* Enough remains have been found as fossils to show that most mammals arose in the Northern Hemisphere and spread southwards.

Upon solitary volcanic islands mammals are rare because of their limited swimming powers, but other animals and plants may have arrived by flying, swimming, or floating upon driftwood. Seeds are carried by birds and wind. Dispersal of animals upon the larger land masses has

* See 'The International Geography,' pp. 83-86.

usually taken place by migration, just as it has in the case of peoples, who, however, are more adaptable than beasts.

3. *The physical changes in climate, earth movements, and so on; and the changes due to the struggle for existence.*

The Alpine flora is frequently found at the summits of mountains at the equator, with the temperate forest-belt below. Their presence is difficult to account for, unless we imagine a cold climate over the lowlands, which gave way gradually, and drove the floras to higher latitudes or up the mountain-slopes to cooler regions.

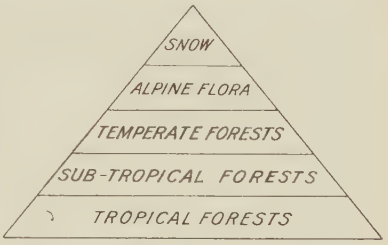


Fig. 27.—Zones of Vegetation on a Tropical Mountain.

The sea is a great barrier to distribution. The fauna upon either side of Wallace's famous line between Bali and Lombok, or Borneo and the Celebes, is so different that this barrier must be very ancient. Again, to explain the remains of the mammoth, horse, and bison found in Alaska, we must assume that Asia was once in connection with America. Geological barriers also account for the peculiar mammalian fauna of Australia, and the strikingly different fauna and flora of New Zealand.

4. *Man.*

The bison and the beaver have been nearly exterminated, and the wolf has disappeared from Britain. Large tracts of South Africa are being depleted of game. The habits of the White man and his diseases have wiped out thousands of coloured folk. The horse was introduced into South America by man after it had previously become extinct there. Clover and other plants have become established in New Zealand, sparrows in America, and rabbits in Australia.

*Climate of the British Isles.**—Near London the annual range in temperature is about 24°; the climate, therefore, is relatively continental in type. In the Inner Hebrides the range is nearer 14°, the climate being more equable on the oceanic border. At the Land's End, where the average temperature is high, and Aberdeen where it is low, the range is between 18° and 20°.

High temperatures occur over the broad eastern parts of the islands in summer, and the isotherms bend to the south over the Irish Sea, because the land is warmer than the sea. In winter the sea is warmest; therefore the isotherms bend to the north over the Irish Sea, and the coldest parts of the land are farthest from the Atlantic breezes. (The English Fens are almost as cold as Aberdeen.) The

* See 'Britain and the British Seas,' by H. J. Mackinder.

FIG. 28.—ISOTHERMS FOR JULY.
(After Buchan.)

FIG. 29.—ISOTHERMS FOR JANUARY.
(After Buchan.)

L. Edna Walter.

FIG. 30.—VIEW ON SOUTH COAST OF ENGLAND, SHOWING DIRECTION OF PREVAILING WINDS (S.W.).

isotherm of 39° runs nearly north and south through Great Britain; everywhere west of it the temperature is raised by winds blowing off the North Atlantic Drift. Winds blow from the south-west for a greater number of days in each month than from all other directions together; therefore the west end of any town is least smoky and best for residence.

The wettest districts are the oceanic borders of Ireland, Scotland, and Wales, for the south-eastern parts of cyclones frequently traverse them, and their high relief aids the precipitation of rain (Fig. 31). Anti-cyclonic conditions are rare in Britain, and usually arise by extension of the European anti-cyclonic area, with east winds, into the lowlands of the south-east of England—by situation and elevation, the driest part of the country, and rarely visited by cyclones (Fig. 32). Rain-shadows occur to the east and north-east of the high ground, although a considerable amount of moisture manages to fall on the leeward slopes and the next elevations in its path. The heavy fall on the western slopes runs quickly to the sea, but the moderate supply on the east runs farther and more slowly, to the benefit of agriculture. Snow falls on the highest ground every winter, but Ben Nevis is usually free from snow in summer.

FIG. 31.—RAINFALL OF THE BRITISH ISLES.

FIG. 32.—DIAGRAM SHOWING THE USUAL PATHS PURSUED BY BRITISH CYCLONES.

(After H. J. Mackinder.)

The thickness of the arrows indicates the relative frequency of the storms.

Sunshine is most frequent upon the dry lowlands in the south-east, but is rare on the clouded uplands. Corn-growing districts are determined by low rainfall and elevation, and much sunshine, and to some extent by the character of the rock, for sand suffers more extremes of temperature than clay, and more readily parts with its moisture. Where the atmosphere is damp and cloudy, oats are generally substituted for wheat and barley. Pasture-grass is the characteristic crop of Britain, nourished by the damp air and frequent rains. It can do with little sunlight, and grows most luxuriantly

FIG. 33.—AGRICULTURE IN THE BRITISH ISLES.

in the lowlands of the west and north, where frosts and droughts are rare and short.

There are three climatic zones of vegetation: (1) east and south-east—lowlands, largely agricultural, and devoted to cereals (Fig. 33); (2) west and north — lowlands, largely pastoral or given to oats; (3) uplands upon which the heavy rainfall allows little soil to accumulate — rock, moor, and bog, clothed with moss, fern, and heather.

Great Britain was clothed with forests in prehistoric times, but little now remains. The bogs and morasses which occupied the clayey plains and peaty moorlands have been largely drained and reclaimed, the most characteristic remnants being the Irish bogs.

CHAPTER V.

The Composition of the Land.

THE lithosphere consists of rocks and rock waste, and 'rocks' include not only the hard masses like granite, but also the soft clays and loose sands. The first rocks were formed by the gradual cooling of the once molten surface of the globe, and separation into minerals which possess, amongst other properties, a definite chemical composition and a definite geometrical crystalline structure. As a rule, however, the minerals of rocks are so closely interlocked that the crystals have interfered with each other's free growth; consequently their outlines are irregular.

The once molten rocks give rise by decay to a second series of rocks, often accumulated in water. Others, again, are formed by the hard parts of once living organisms.

Thus we have—

1. Sedimentary rocks.
2. Igneous, or fire-formed rocks.

1. **Sedimentary Rocks.**—Rocks laid down under water, as well as blown sands, volcanic dusts and ashes, and rocks of organic origin.

Those which consist of fragments of earlier rocks (igneous or sedimentary) are termed 'fragmental.'

The most important sedimentary rocks are as follows :

(*a*) **The Coarser Fragmental Deposits**, formed chiefly by running water.

Shingle.—Coarse, rounded, water-worn stones of the river-bed or sea-beach.

Gravel.—Smaller rounded stones, often mixed with sand.

Sand.—Water-worn detritus on a still finer scale, varying in size from small shot to just visible fragments. Most sands consist largely of quartz, a mineral which survives better than most of the other common minerals of igneous rocks. The larger grains tend to be rounder than the smaller ones, and both sea and river sands are usually more angular than wind-blown sands (p. 63).

Sandstone.—Cemented and compacted sand. The commonest cement is ferruginous or iron-bearing, and gives rise to various colour-shades in red, brown, yellow, or green. Other cements are argillaceous or muddy, calcareous or limy. Siliceous sandstones are cemented by silica. Some cements are due to the recrystallization of some of the constituents of the sandstones, others are introduced by infiltering waters.

Grit.—A rather coarse sandstone, in which the grains are angular and vary a great deal in size.

Conglomerate.—Consolidated gravel or shingle.

Breccia.—Similar in appearance to conglomerate, but the fragments are angular.

(*b*) **The Finer Fragmental Deposits** consist of the fine washings of the land, and form a mud belt, extending 100 to 600 miles from the coast-line. Mineral changes take place in the muds as they lie upon the sea-floor, so that the resulting product may be different to what it was when first laid down.

Clay.—Largely formed of the flaky decomposition products of felspars—kaolin and micas—with fragments of other minerals. The colours of clays are mostly due to iron compounds. Clay is soft and crumbly when dry, and gives off an earthy smell if breathed upon. When moistened, it becomes plastic, and can be worked with the fingers ; with much water it becomes mud. The addition of sand or carbonate of lime makes a sandy or calcareous clay. Mudstone is a compacted clay ; shale, a clay deposited in thin layers or laminæ along which it will split.

Loams.—Sandy clays mixed with more or less organic matter ; found in the flood-plains of streams and upon hill-slopes.

Boulder Clay.—Fine rock flour full of stones ; the result of ice action.

Slates.—Hardened clay rocks which will split into thin layers parallel to each other, an effect due to earth movements, which have produced new structural planes (cleavage planes) at right angles to the pressure.

(*c*) **Fragmentary Rocks of Volcanic Origin** (Pyroclastic Rocks) are the result of explosive volcanic action, and consist of volcanic matter frequently mixed with ordinary sediment or shattered rock. The finer rocks—tuffs and ashes—commonly possess a laminated structure, especially when laid down in water, and may have a calcareous, ferruginous, or siliceous cement. Coarser types are volcanic 'breccias' and 'agglomerates' (**Fig. 64**).

(*d*) **Rocks of Organic Origin**—*Limestones.*—Carbonate of lime mixed with various impurities, and largely composed of fragments of calcareous organisms, such as algæ, foraminifera, corals, sea-urchins, and crinoids (sea-lilies), the hard parts of crustaceans, and shells of sea and fresh water mollusca. In addition, there is a calcareous paste or mud in which the fragments are embedded. In chalk the

bulk of the rock consists of very fine calcareous material, such as would come from the destruction of shells, corals, etc., and there are also calcareous algæ, as well as complete shells of mollusca, foraminifera, and so on.

In a dolomite one half of the lime is replaced by magnesia.

Oolite.—A limestone, containing little rounded spindle-shaped or spherical grains, each built up of layers of calcareous material like the coats of an onion.

Carbonaceous Rocks are due to the decay, sealing up, and consolidation of vegetation, which, when mingled with sediment, become carbonaceous shale.

Peat.—Vegetable matter more or less decomposed and considerably altered covers extensive areas in the peat bogs and swamps in temperate climates, in some

W. Lawrence, Dublin.

FIG. 34.—TURF-CUTTING IN DONEGAL.

places attaining a depth of over 50 feet. The upper layers of a peat bog are light-coloured and the vegetable origin is obvious ; deeper down the layers are darker in colour, whilst at the bottom they are almost black (' stone-turf ') and have lost all signs of vegetable origin.

Lignite (brown coal, pitch coal).—A connecting link between peats and low-grade coals.

Coal.—Distinct layers, along which charred vegetable tissue, leaves, leaf-stalk, and bark or wood are often visible. The vegetation has become altered by chemical action, heat, pressure, and folding of the rocks, so that it is richer in carbon than before. Coal is found in seams averaging 4 to 6 feet in thickness, and bedded between sediments which have been laid down under water and near land. When a fire-clay underlies a coal-seam it often contains rootlets of trees (*Stigmaria*) which

have helped to form the seam ; and this is taken as a proof that the seam in question was formed on land and the tree always occupied its present position (' growth *in situ* '). Other seams are undoubtedly due to accumulation of drifted vegetation beneath the waters of lakes, estuaries, or seas (' drift origin ').

Bog-Iron Ore.—Due to separation of iron from water by diatoms, and secretion of the same within their skeletons.

FIG. 35.—FOSSIL OF FERN IN A CARBONIFEROUS ROCK.

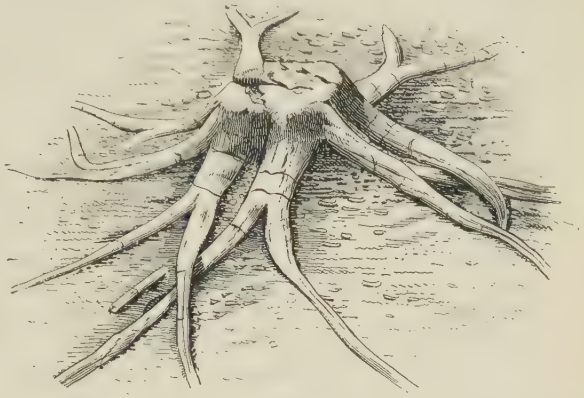


FIG. 36.—STUMP AND ROOTS OF A FOSSIL TREE (*Stigmaria ficoides*) FROM THE CARBONIFEROUS SANDSTONE. (After Williamson.)

The diameter of the stump is 4 feet 4 inches, and the spread of the roots 28 to 30 feet.

Amongst the rocks of sedimentary and **chemical** origin we may mention rock salt, gypsum, limestones, tufa, stalactite, stalagmite, some oolites, dolomites, ironstones, and siliceous sinters.

Accumulation of Sedimentary Rocks.—If a tumbler filled with muddy water is allowed to stand, the sediment accumulates at the bottom

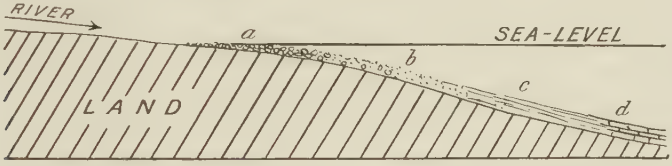


FIG. 37.—ACCUMULATION OF SEDIMENTS UPON THE SEA-FLOOR.

a, shingle ; *b*, sand ; *c*, muds ; *d*, limestones.

in layers, the heavier particles sinking at once, the finer ones in gradation afterwards. If more mud be added to the now clear water, a second series of layers will be formed upon the first. In a similar manner, the washings from the land carried by rivers into seas and lakes accumulate upon their floors ; the heavier detrital deposits settle close to the river-mouth, the

sands are swept farther out, and the muddy matter—in a fine state of suspension—may travel for miles before it finally comes to rest. Beyond the reach of such sediments pure limestones (often formed in fairly shallow water) and deep-sea deposits will accumulate (Fig. 37).

The sea-floor is so large that if only a small portion is studied it seems to be practically flat; hence the layers of sediment will be nearly horizontal, and as fresh supplies are washed down by rivers, a series of these horizontal layers, or strata, will accumulate on the sea-bed. Although originally laid down as loose, incoherent deposits, we usually find the stratified rocks compacted into conglomerates, sandstones, clays, shales, or limestones—a result brought about partly by pressure of overlying strata, and by uplift and draining off of the water, and partly by the formation of a cementing material.

Planes of stratification divide the surface of one layer from the bottom of the succeeding one. They are of two kinds: (*a*) planes marking the boundary between layers of different sediments, like sand and clay; (*b*) planes representing a pause in the deposition of sediment, when the lower bed may become hardened on the surface before the second bed (possibly of similar sediment) is laid upon it. If the layers are less than 1 inch in thickness, the rock is said to consist of 'laminæ,' separated by 'planes of lamination'; the Humber warps, for example, are fine laminated muds deposited one layer at each high tide, the surfaces being dried at low tide.

Fig. 38.—Production of Current-Bedding.

Bedding is usually well marked in sands, although there is not very much lamination. Should, however, the sands be accumulated by swiftly moving waters which often change their directions (*e.g.*, in estuaries and straits), the laminæ are inclined, because if for any reason there is a dip in the floor of a channel, the current, coming into deeper water, is checked in velocity, and drops sediment which falls down the slope and rests layer over layer, whilst larger pebbles roll to the bottom and form a seam parallel to the general bedding. A slight change in the direction of the current causes the new layers to tilt in a different direction (Fig. 38). This effect is called 'false' or 'current-bedding.'

Stratification planes of shallow-water deposits frequently bear ripple-

marks like those upon the beach ; and further evidence of formation in water is furnished by the presence of numerous fossils.

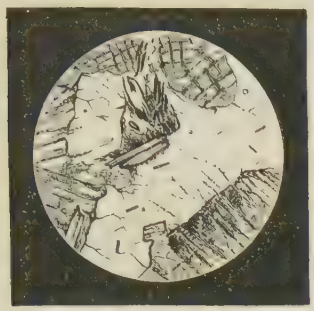


FIG. 39.—MICROSCOPIC STRUCTURE OF GRANITE.

(From 'Encyclopædia Britannica.')

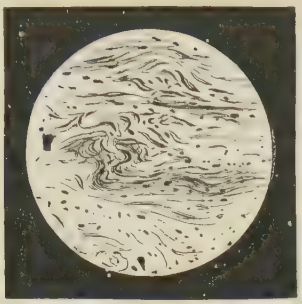


FIG. 40.—MICROSCOPIC STRUCTURE OF OBSIDIAN (a volcanic glass).

(From 'Encyclopædia Britannica.')

2. **Igneous Rocks.**—The igneous rocks cooled from a state of fusion may, for our purpose, be classed as follows :

(*a*) **Major Intrusive Rocks** (Plutonic Rocks).—Large rock masses which have consolidated at considerable depths from the surface, cooling slowly under great pressure. They consist entirely of mineral crystals of nearly the same size, with no glass, and the texture may be rather coarse, like that of granite.

(*b*) **Minor Intrusive Rocks.**—Smaller intrusive masses which have consolidated at depths nearer the surface, and have therefore cooled more quickly and under less pressure ; they serve as a link between the Plutonic and

(*c*) **Effusive Rocks** (Volcanic). — Consolidated at the surface of the earth, cooling quickly at low pressure. Rocks in which large crystals are often set in a fine crystalline ground, or in glass, the larger crystals being formed whilst the molten ground-mass was far below the surface, and floated up in it at the time of the eruption.

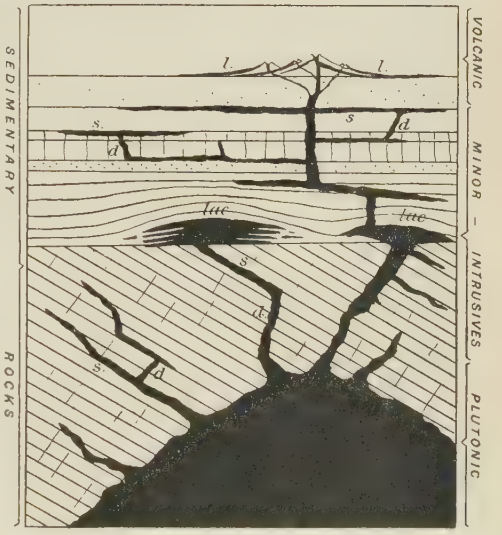


FIG. 41.—DIAGRAM SHOWING THE RELATION OF THE IGNEOUS ROCKS TO ONE ANOTHER AND TO THE SEDIMENTARY ROCKS.

d, dyke ; *s*, sill ; *l*, lava ; *lac*, lens-shaped masses or clusters of sills.

These three divisions pass gradually one into the other, so that no hard-and-fast line can be drawn between them; but the volcanic rocks at one end are quite easily distinguishable from the plutonic rocks at the other (Fig. 41).

The plutonic rocks form large masses which have been brought to light by earth movements and removal of the overlying cover of sediments; they are in some cases the cooled reservoirs which were the feeders of volcanoes. The minor intrusions form *dykes* and *sills*. A

H.M. Geological Survey.

FIG. 42.—DISTANT VIEW OF BENNAN HEAD: A SILL OF DOLERITE INTRUSIVE IN TRIASSIC SANDSTONE.

On the foreshore, parallel dykes of dolerite; in foreground, a raised beach. Kildonan, south-east coast of Arran.

dyke is a wall-like mass of rock, thrust, when in a molten state, into a fissure cutting across the rocks at a high angle. A sill is a similar sheet, lying parallel, or nearly parallel, to the planes of stratification. The volcanic rocks consist, not only of sheets of lava poured out at the surface, but of dykes and irregular masses plugging the throats of volcanoes (p. 53).

Metamorphic or Altered Rocks consist of igneous and sedimentary rocks influenced by heat, pressure, or both combined, resulting in the production of new minerals and new structures. They cover thousands of square miles in the British Isles, especially in the Highlands and the North of Ireland.

CHAPTER VI.

Earth Movements, Volcanoes, and Earthquakes.

From the exposed faces of cliffs or cuttings it is evident that in many cases rocks, originally horizontal, are now inclined at various angles. Such exposures are natural sections. A *geological section* is therefore one we should see, or expect to see, if a cutting were made through the rocks

H.M. Geological Survey.

Fig. 43.—A Sharp Anticline in Coal Measures, Planed by the Action of the Sea.

Near Saundersfoot Harbour, Pembroke.

along the desired line of section. Since sedimentary rocks, enclosing remains of marine organisms, are now often thousands of feet above sea-level, we must admit that large earth movements have taken place. If the movements had been simply up and down, sections would show horizontally bedded strata; they are, however, sometimes actually

standing on end—a proof that more complex movements have occurred. Instead of the highest beds only appearing at the surface, lower ones are brought into view.

The *outcrop* of a bed is that part which is exposed at the surface. The *dip* is the direction of its steepest inclination; it varies from 0° (horizontal) to 90° (vertical). The *strike* is a horizontal line drawn at right angles to the direction of dip.

Inclined beds are generally parts of rock folds whose tops have been swept away (Fig. 44). An *anticline* (or upfold) is one in which the beds are folded over an imaginary axis from which the beds dip away upon both sides. A *syncline* (or downfold) is the reverse—the beds dip towards, and under, a central axis. If the top of an anticline or syncline

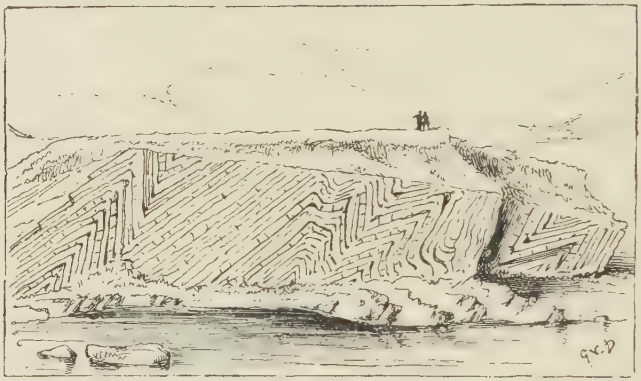


FIG. 44.—ANTICLINES AND SYNCLINES (ASYMMETRIC AND SOMETIMES INVERTED) IN LIMESTONE AND SHALE, LOUGHSHINNY, COUNTY DUBLIN.

be cut away, two parallel outcrops of each bed are exposed at the surface (Fig. 43), in one case dipping outwards from, and in the other inwards to, the central axis.

In the above examples the folds are 'symmetric,' but should the dip be greater upon one side than the other, the fold is said to be 'asymmetric.'

A combination of anticline and syncline forms an 'earthwave'; if the earth-pressure has been great, the limb common to both anticline and syncline is inverted, producing an overfold (Fig. 44).

In *domes* and *basins* the rocks dip away from or towards a central point, instead of a central axis. If elongated, they become elliptical, and the central parts behave very much like simple anticlines and

synclines. The Weald of Kent and the London District are good examples of dome and basin structures (Fig. 111).

A *monoclinal fold* is one in which the common limb is very steep, but the upper and lower limbs are gently inclined.

Joints.—All rocks are affected to a certain extent by joints, which are actual breaks or dislocations due to tension or shock. Joints are typically developed in well-bedded rocks, such as limestones and sandstones, which commonly possess two well-marked sets (master-joints) at right angles to each other and to the stratification planes, thus splitting up the rock into rectangular blocks or cubes. There are also numerous minor joints traversing the rock in all directions. Master-joints facilitate the work of quarrymen, but play a much greater part in the quarrying operations of Nature in affording channels open to destructive atmospheric agents. Many granites have a rough cuboidal jointing, well seen in the Dartmoor district (Fig. 72).

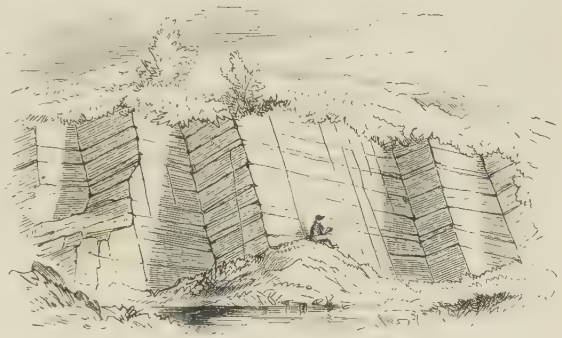


Fig. 45.—Joints in Limestone Quarry near Mallow, County Cork.

Shrinkage-joints are found chiefly in igneous rocks, although not confined to them, for mud flats exposed to the sun soon develop shrinkage-cracks, splitting up the surface into cakes which curl up at the edges. The regular form most freely assumed is that of a hexagon, although irregularities in drying and composition give rise to figures having more or less sides. A familiar example of shrinkage-jointing is afforded by starch, which splits into small straight columns, each having several sides.

In igneous rocks the cooling has frequently been conducted so regularly that the joints break up the rock into straight-sided prisms, perpendicular to the cooling surfaces, and are therefore horizontal in vertical, and vertical in horizontal, beds. Very beautiful examples occur amongst the basaltic lavas of the Giant's Causeway (Fig. 46; see also Frontispiece).

'The columnar bed that forms the Causeway is . . . about 60 to 70 feet thick; and, while perfectly regular in its columnar structure at the Causeway and the "Organ," assumes farther eastward the confusedly starch-like arrangement of

A. T. Metcalfe.

FIG. 46.—THE GIANT'S CAUSEWAY.

Sheets of columnar basalt weathering into 'chimneys' on the skyline.

prisms already referred to. But in the great cliff section of the Amphitheatre, the more regular structure is resumed: the bed swells out to about 80 feet in thickness, and columns of that length run up the face of the precipice, weathering out at the top into separate pillars, which, perched on the crests of an outstanding ridge, are known as "chimneys."'*

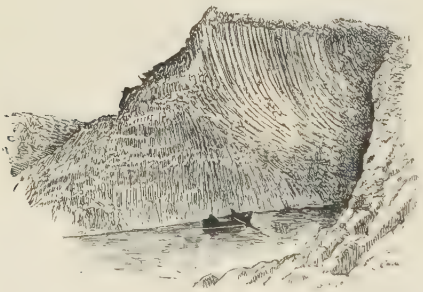


FIG. 47.—THE CLAM-SHELL CAVE, STAFFA.

The columns may be segmented by cross-joints, which sometimes take a ball-and-socket form; occasionally they are curved, as at the Clam-Shell Cave, Staffa (Fig. 47).

Faults are fractures of the rocks, with displacement of the beds on each side of the fracture. That part of the broken bed which is in the higher position is said to be on the upthrow side of the fault; the other is the downthrow side.

* Sir A. Geikie.

The commonest types of faults are—

(*a*) *Normal Faults.*—The fault fissure slopes towards the downthrow side, or is vertical.

(*b*) *Reversed Faults.*—The upthrow side overrides the downthrow side.

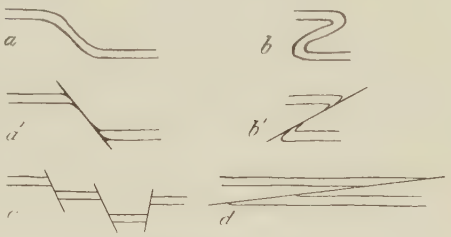


FIG. 48.—FAULTS.

a, simple fold passing to normal fault *a'*; *b*, over-fold passing to reversed fault *b'*; *c*, step-faults: *d*, overthrust.

These faults may be due to movement along joints, but are usually produced by a break along the middle limb of a fold, the displaced beds being often turned into, and drawn out along, the fault plane. A series of faults, normal or reversed, gives rise to 'step-faulting.'

(*c*) *Thrusts* are exaggerated reversed faults, in which the middle limb of the reversed fold was nearly horizontal, and has been quite obliterated by the movement.

Faults are important because of their influence, in certain cases, upon physical features. If the fissure is a ragged one, broken rock will partly fill it and form a fault-breccia, which may yield to the weather more easily than the surrounding rock. On the other hand, mineral waters may filter in and cement the breccia into a very resistant rock. Faults bring soft rocks against hard rocks, and may thus give rise to differences in surface features, to change in circulation of underground waters, and so on; but, on the whole, they are not very visible at the surface, since the part upthrown is often worn level with that downthrown (Fig. 50).

B. Smith.

FIG. 49.—A NORMAL FAULT IN THIN-BEDDED LIMESTONE, VALE-OF-CLWYD.

Notice tree growing in fault-plane.

Other Movements.—A further proof of earth movements is furnished by the uneven deposition of strata, one upon another. The lower beds have been elevated and tilted, their edges have been worn away to a level surface, and another deposit spread over them. Such an arrangement is called an *unconformity*, the younger bed being 'unconformable'

to the older ones. If the old surface is slightly tilted, the newest bed will creep across the one below, overlapping it and extending a little farther upon the slope (Figs. 51 and 52).

Evidences of recent elevations and depressions are abundant. Old beaches of sands and shingle, with marine shells, are found at different points round the coast-line at various heights (Fig. 204) up to 150 feet above present sea-level, and old sea-cliffs, with their caves, now stand many miles from the water's edge. Our estuaries are drowned valleys, shaped at a time when the country stood at a higher level than at present, and submerged forests repeat the story. In the northern parts of the Baltic land is slowly emerging from the waters, whilst in the south it is disappearing from sight.

FIG. 50.—DIAGRAM OF A FAULT WITH FAULT-BRECCIA.

Owing to contraction and settling down, parts of the earth's crust have been squeezed and ridged up to accommodate the sinking portions, so that much greater earth movements than those discussed above have taken place, and these may be classed according to degree of size. The larger movements are of the nature of long, swelling earth-waves;

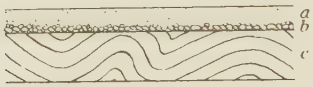


FIG. 51.—DIAGRAM OF AN UNCONFORMITY.

a, sand; *b*, conglomerate; *c*, older rocks.

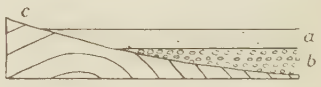


FIG. 52.—DIAGRAM OF UNCONFORMITY WITH OVERLAP.

a, sand; *b*, conglomerate; *c*, older rocks.

the crests forming the *continents*, the troughs the *oceans*. The common limb of the wave is frequently steep, and may be a line of weakness, along which faulting and thrusting is common. As the contraction went on, smaller but still relatively great movements of a similar nature wrinkled the surfaces of the continents, and gave rise to *mountain structures* (Chapter X.).

Volcanoes and Earthquakes.

A volcano is an opening or vent in the earth's crust through which gases and rocks in liquid and fragmental state are erupted from the heated interior, and poured out at the surface. The eruption may (but not of necessity) result in the production of a hill or mountain. In past

times the ordinary volcanic mountain was supposed to be a pustule or bubble due to gases and hot lavas forcing up the surface, and was known as *a crater of elevation*. It was noticed, however, that these hills grew in

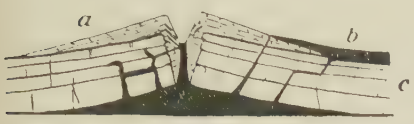


FIG. 53.—DIAGRAM OF SUPPOSED 'CRATER OF ELEVATION.'

a, ashes ; *b*, lava ; *c*, solid rocks.

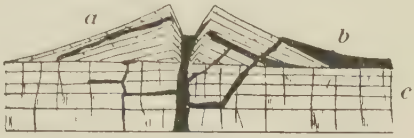


FIG. 54.—DIAGRAM OF 'CRATER OF ACCUMULATION.'

a, ashes ; *b*, lava ; *c*, solid rocks.

size by accumulation of the ejected matter, and the question arose whether the hills had or had not been entirely formed in this manner, or were *craters of accumulation*.

Active volcanoes may be classified as (1) central volcanoes ; (2) puys ; (3) fissure eruptions.

(1) **Central volcanoes** are cones built of materials thrown out by successive eruptions about a central orifice. Steam is often poured out in immense quantities, and condenses to form heavy cloud and rain.

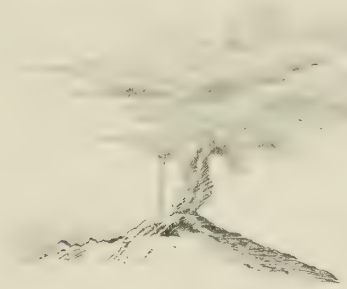


FIG. 55.—THE SUMMIT OF EREBUS. (After E. A. Wilson.)

Condensed steam from several vents ; cloud masses formed above.

Stromboli, the 'Lighthouse of the Mediterranean,' puffs it out spasmodically ; from Vesuvius it is emitted in mighty volumes, which assume a cauliflower-like appearance, similar to the steam from a locomotive. *Volcanic ashes* and *lapilli* are small pieces of rock, mineral crystals, or fragments of molten lava, blown into the air by the explosive action of the steam ; cooling as they fall, they descend as small stones and dust. The larger and heavier fragments naturally fall first, and accumulate

close to the vent (whose open mouth is called the *crater*), building the cone higher and more rapidly than the parts farther away where the finest fragments fall. The ashes of the cone slope inwards towards the vent, and also outwards down the mountain-side, lying at the angle of rest. Pieces of lava, called *volcanic bombs*, are frequently hurled high in the air, and, whilst revolving, take on a cooled crust, which may remain intact when they fall.

FIG. 56.—A VOLCANIC BOMB. (After Jukes.)

The bomb, in falling, has pressed down the underlying bedded tuffs.

Central volcanoes also eject lava, which becomes sandwiched between the layers of ashes. Furthermore, subsidence of the volcanic pile, owing to its weight and the drain upon the supply of liquid rock, may set up cracks which radiate from the centre. Instead of flowing from the crater, the lava now issues from, or consolidates in, these fissures, giving rise to strong plate-like dykes, which bind the whole mass together on a girder-like principle; and, since they are usually harder than the ashes, they stand out like walls when weathered.

When escaping from a vent, lava is red hot, and usually gives off clouds of steam. As it flows along, its upper surface is quickly cooled, becoming cindery and broken because movement still goes on below; and with relief of pressure steam cavities, called 'vesicles,' are formed, more particularly in the crust of the stream. A lava with an irregular vesicular surface is said to be 'slaggy'; if extremely irregular, 'scoriaceous'; and similar fragments ejected from the vent are *scoriæ*. *Pumice* is a lava full of steam cavities, and for this reason is frequently found floating in the water about volcanic islands. Other lavas have a smooth, ropy, or pitch-like surface.

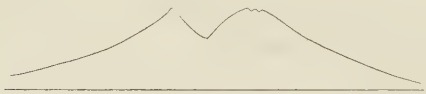


FIG. 57.—VESUVIUS AND SOMMA. (After Judd.)

Outline in 1881, solid line; outline before eruption of A.D. 79, dotted line. Monte Somma is the remnant of the old Caldera.

Ordinary craters of central volcanoes are comparatively small; large craters, or 'calderas,' are due either to (*a*) the blowing off of the top of the volcano—an event which happened to Vesuvius in A.D. 79, and gave rise to the encircling crater-ring of Monte Somma, within which the present cone is built; (*b*) the collapse of the top, slice by slice, and its

engulfment in the sea of boiling lava within—as is the case in the Haiwaian volcanoes, the caldera of Kilauea measuring $2\frac{1}{2}$ by $1\frac{3}{4}$ miles.

The shape of the cone is due partly to its composition (whether of ashes, lava, or a mixture of the two) and partly to the type of lava and manner of eruption (Fig. 60). A cone of ashes makes a grand and shapely mountain, gradually increasing in steepness upwards, such as Fuji Yama, Japan, whose angle of slope is about 20°. Should there be a pile of agglomerate beneath the ashes, the slope will be greater.

FIG. 58.—VIEW OF THE BAY OF NAPLES WITH MONT SOMME (left) AND VESUVIUS (right).

When much lava is present, the mountain may be round-shouldered, like Etna, because the lava often issues from parasitic cones on the sides, and consolidates before flowing very far.

Some lavas are light, sticky, and viscous, and will not flow far. In the Auvergne, the Isle of Bourbon, and elsewhere, there are roundish hump-like cones entirely formed of such lava, with an internal onion-like structure, caused by successive injections of lava within the still soft outer coats.

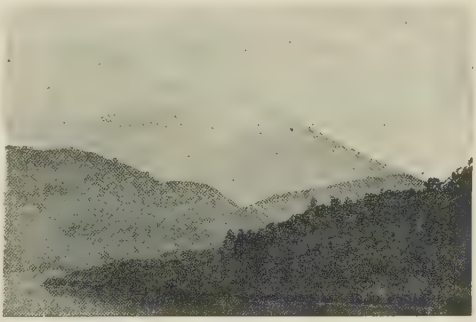


FIG. 59.—FUJI YAMA, JAPAN.
(From Del Mar's 'Around the World through Japan.')

The Haiwaian volcanoes —the largest in the world— are built of very liquid basaltic lavas, which flow for miles before cooling. The cones have a very gentle slope —6° to 8° only—but are so large that they are 70 miles in diameter, with a height of nearly 14,000 feet (Mauna Loa). The volcanic action is not explosive; the lava rises until it finds a crack in the caldera side, through which it flows.

Lavas most commonly connected with explosive activity are neither

very sticky nor very fluid (called *Andesites*, from their prevalence in the Andes); hence the shape of the cone will depend upon the relative proportions of lava and fragmentary matter present. The eruptions of La Soufrière and Mont Pélé (West Indies) were of this type, and well illustrate the explosive character of the outbursts. La Soufrière's crater-lake was completely destroyed, and the rising lava of Pélé blown to fragments* by included steam and gases, and hurled over the crater's lip, whence it descended upon St. Pierre as an incandescent cloud, permeated throughout by the poisonous exhalations of the volcano.

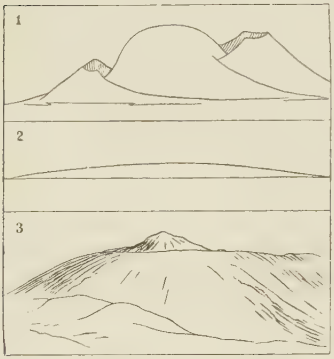


FIG. 60.—OUTLINES OF VOLCANIC CONES. (After Judd.)

1. Grand Puy of Sarcoui: an acid lava, between two breached scoria cones. Auvergne.
2. Mauna Loa: basaltic lava, with a base of seventy miles. Haiwaii.
3. Etna, from the Val-del-Bove.

Probably the most stupendous eruption of modern times was that which, in the year 1883, wrecked the island of Krakatoa, in the Straits of Sunda. On August 27 four explosions, of fearful intensity, shook earth and sea and air, and about two-thirds of the island was blown completely away, together with most of the cone of Rakata.

(2) **Puys** typically developed in the Auvergne, the Eifel, and the Phlegraean Fields—are clusters of cinder-cones and lava-domes. Some of the cones are remarkably perfect, and still show broken crater-rims from which lava was discharged.

If we indicate the position of volcanoes on a large-scale map, it will be seen that the *vents often occur in lines*, many of which are known to be lines of weakness in the earth's crust. Thus the volcanoes of the Lipari Islands are on fault lines, and the Antilles (West Indies) are the summits of a submerged mountain-chain on the crest of a great earth-wave. The Andes are on a similar fold, and so are the islands of Japan. Erebus and Terror also lie near a break in the earth's crust. This linear arrangement of volcanoes leads to the third type, one whose vent is itself a long fissure.

(3) **Fissure Eruptions.**—The action consists in the welling up of basaltic lava through opening cracks which are finally concealed by the outpouring liquid. These lavas have been said to flow at phenomenal

* The dust and ashes were rapidly washed out to sea to form a stratified tuff.

speeds, but this may be accounted for if we remember that at one place along the fissure lava may be at the surface, whilst a mile away it is only 20 feet below, and rising rapidly. In many cases piled-up blocks of lava, or rows of small cinder or lava-cones, never more than 200 feet high, are formed along the fissure (Fig. 62).

The western stream from the Laki eruption (Iceland) of 1783 flowed for upwards of 40 miles, and within historic times valleys 600 feet deep have been filled to the brim. Out of 107 volcanoes in Iceland, 83 were fissures, 16 dome-shaped, and only 8 of the explosive type. In New Zealand (North Island) the fissure eruption of Tarawera, in 1886, buried the famous pink-and-white sinter terraces of Rotomahana.

Many eruptions have taken place beneath the sea. At intervals there have arisen, from quite deep waters, volcanic piles with projecting tops, forming islands, about whose shores marine sediments are interstratified with the ejectamenta of the volcanoes.

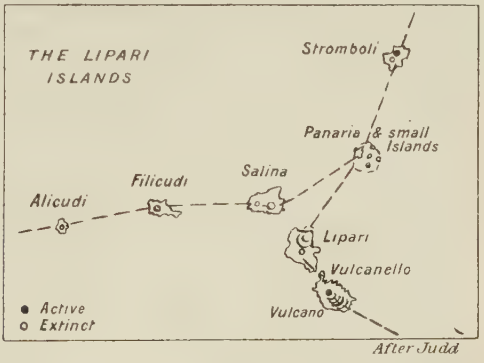


FIG. 61.—LINES OF FRACTURE UPON WHICH THE VOLCANOES OF THE LIPARI ISLANDS ARE SITUATED.

Some islands, like Santorin, in the Grecian Archipelago, are parts of the old crater or caldera rim, just rising above sea-level. In 1831 Graham's Island, a cinder-cone 65 metres high, with a crater containing water, was thrown up 30 miles off the coast of Sicily, but was destroyed by the waves in four months, probably because there was little or no lava to give it stability. Again, in 1891, an eruption took place near Pantellaria in the strait which is on a line of fault between Sicily and Tunis. This so-called 'Foerstner volcano,' however, did not build a structure above the water, but emitted black pillow-like bombs of hot lava, which floated about, hissing and steaming, until they finally burst and sank.

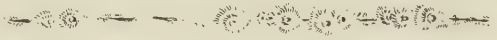


FIG. 62.—SMALL CONES ON A LINE OF FISSURE.

When the volcanic energy of a region is dying out, 'solfataras' take the place of volcanoes proper. *Solfatara*, a volcano in the Phlegraean Fields, near Naples, has been dormant for centuries, but emits steam and acid vapours (*e.g.*, carbonic acid gas), which give rise to chemical deposits. This name, therefore, is applied to similar occurrences elsewhere.

Hot springs, sometimes due to heat developed by earth movements, are, as a rule, connected with volcanic eruptions, and, together with geysers, are the last signs of volcanic activity in a region. The subterranean waters become hot and fitted to hold in solution mineral matter which may be deposited when the water issues and cools at the surface. Hot springs, depositing siliceous or calcareous sinter and often forming beautiful, translucent, coloured basins and terraces, occur in the volcanic districts of Iceland, New Zealand, and the Yellowstone Park, U.S.A.

J. H. Rowntree.

FIG. 63.—WAIROA GEYSER, NEAR LAKE TARAWERA, NORTH ISLAND, NEW ZEALAND.

Geysers, found in the same districts, are openings from which fountains of hot water and steam are erupted at regular or irregular periods. An underground pipe communicates at the surface with a circular orifice, usually surrounded by a crater-like sinter basin or cone. The eruption is caused by overheating at the bottom of the pipe, where the water is above the boiling-point but is prevented from flashing into steam by the pressure of the column above. Water then overflows from the pipe into the basin until the pressure below is lessened, when steam is suddenly formed and the explosion occurs. Probably the largest geyser in the world was Waimangu, in New Zealand (1904).

Cause of Volcanic Action.—The cause of volcanic action may be traced to the interior heat of the earth. The lithosphere in cooling

is compressed into folds, the relief thus obtained being distributed unequally. Under diminished pressure the heated interior is allowed to pass into the liquid state along the lines of relief; thus volcanoes are chiefly distributed along the borders of land sloping steeply beneath the sea. Some portions of the crust have served time after time for the escape of volcanic energy, whilst others close by have been unaffected. The fault-lines bounding ancient depressions seem to favour the sites of vents, and once the vents are established, continuous contraction will always be forcing molten rock to the roots of the volcanoes.

In a subsiding area, blocks of rock, sinking or becoming tilted, allow the lava to gently well over the sunken portions. Explosive action is due to gases (especially steam), dissolved and absorbed by the lava under great pressure, suddenly expanding on relief of pressure. Explosions may also be caused by sea water leaking down to the heated lava.

FIG. 64.—AGGLOMERATE WITH VOLCANIC BOMBS (light patches) NEAR THE MONASTERY, CHARNWOOD FOREST, LEICESTERSHIRE.

Ancient Volcanoes of Britain.* —Probably no region in the world is better fitted for the study of past volcanic activity than the British Isles, situated on the edge of a continent where earth movements of various geological ages have been accompanied by eruptions on the grandest scale. Volcanoes and erupted material were denuded, buried up, or uncovered, like ordinary rocks; the softer materials of the cones were stripped away, leaving the harder central masses in solitary isolation as *volcanic necks;* the seas, working laterally, have exposed them in section, and laid bare their very roots. Examples of all types occur in such numbers that only a few cases can be mentioned here.

The old rocks of Charnwood Forest, Leicestershire, are the summits of a buried mountain-range peeping through the blanket of younger rocks which enwrap them.

* Described in detail in Geikie's 'Ancient Volcanoes.' Their distribution may be traced upon any good geological map.

The volcanoes were probably submarine or insular, because ordinary sediment is mixed with the débris, which has since been compressed, folded, and sculptured into mountains. Peldar Tor consists of rock which has cooled in a vent; it is surrounded by agglomerates, ashes, and tuffs—coarse near the vent, but becoming finer in a radial direction.

Snowdon is composed mainly of three lava flows, capped by a volcanic ash with marine fossils, and neighbouring summits exhibit a similar structure.

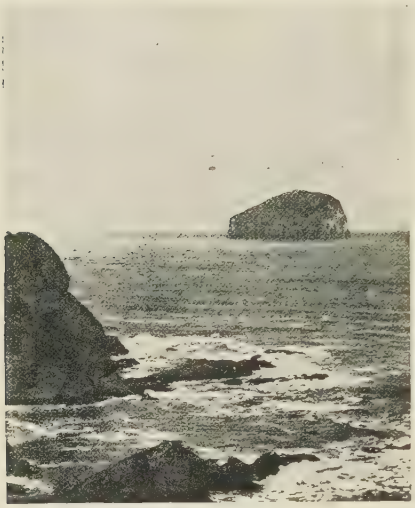


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FIG. 65.—THE BASS ROCK, HADDINGTONSHIRE.

A volcanic neck consisting of lava which filled the vent of a volcano of the carboniferous period.

The English Lake District was another great centre. The whole of the ground between Skiddaw in the north and Coniston in the south is volcanic. The Gable, Great End, the Langdale Pikes, and Scafell summits are sculptured from compacted ashes and agglomerates.

Volcanoes were arranged in two parallel lines, about 20 miles apart, on the opposite sides of a great depression (Lake Caledonia) in the Scottish Lowlands during the Old Red Sandstone Period. The materials of the Sidlaws, Ochill, and Pentland Hills were ejected from these vents, the chief of which lay near Stirling, where one agglomerate is 1,000 feet thick (see p. 175).

The district of Fife and the Lothians must once have resembled the Auvergne, where puys are so well developed, because the sedimentary rocks are pierced by dykes and necks, filled with volcanic ash or basalt (Fig. 66), and interstratified with small sheets of basalt and tuff.

The most recent volcanic activity in Britain is noteworthy because the eruptions were of the fissure type. The 40,000 square miles of district affected comprises the North of England and Ireland, the Western Isles of Scotland, and extended to the Faroes and Iceland. The basalt plateau of Ulster is only a portion of this area, which has been to a great extent destroyed, but remnants of it are found in Skye, Mull, Eigg, Rum, and other places (Fig. 140). Thousands of fissures, generally running north-west to south-east, opened out, and lavas welled over, sheet upon sheet, until several thousand feet accumulated. Great masses of gabbro and granite were then intruded into the basalts, and were followed by sills and a second series of parallel dykes, some of which never reached the surface.

FIG. 66.—DIAGRAM OF A VOLCANIC NECK. (After Jukes.)

Earthquakes.—Anything causing a sudden jar, such as a blast of dynamite in a quarry, will produce tremors in the earth's crust. An earthquake is a natural subterranean shock, giving rise to waves of elastic compression, which radiate from the centre ('focus' or 'centrum') in all directions as concentric spheres. The point where the waves first reach the surface is the 'epicentrum,' from which they move outwards in ever-widening circles, like those from a stone dropped into water.

At the epicentrum the movement is up and down; farther away it is in the direction of a line joining the centrum to the point in question.

Places at which the severity of the shock is the same may be joined by so-called 'isoseismic' lines, which should form circles about the epicentrum. Since, however, the earth varies in composition, the waves —and therefore the isoseismic lines—become distorted, travelling, for example, twice as fast in granite as in sand.

At a distant spot the earthquake is heralded by preliminary tremors, caused by waves passing *through* the earth; these are followed by a larger wave motion travelling *round* the earth, and the shocks are then repeated by faint oscillations, or 'earthquake echoes,' which mimic the larger vibrations. Other waves produced by earthquakes are: (*a*) An air wave, with a rumbling noise; (*b*) a sea wave, if the quake is submarine; (*c*) large destructive waves near the epicentrum, caused by loose soils being thrown into visible vibrations, which tilt building cause trees to sway backwards and forwards, and fissure the ground so that houses may be actually engulfed.

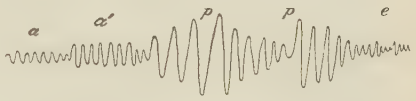

FIG. 67.—AN EARTHQUAKE RECORD.
a, *a'*, preliminary tremors; *p*, *p'*, the shock; *e*, echoes.

In spite of the fact that earthquakes frequently accompany volcanic action, *most volcanoes lie outside the great earthquake centres.* We may classify earthquakes as (1) volcanic quakes; (2) dislocation quakes, due to strain followed by a sudden jerk along faults which are often seen to accompany the shock.

1. *Volcanic quakes,* although severe at the epicentrum, are local in their effects, and have very shallow centra. The explosion of Krakatoa did not shake Batavia, 90 miles away, to any great extent; nor were any far-reaching shocks noticed during the eruptions of Pélé and La Soufrière in 1902.

E. E. L. Dixon.

FIG. 68.—RIFT CAUSED BY THE SAN FRANCISCO EARTHQUAKE, 1906.

View looking westward along fence broken by the rift, which crosses it obliquely.

FIG. 69.—EARTHQUAKE SPOTS IN THE BRITISH ISLES.

(After De Montessus de Ballore.)

Size of spots indicate the number of earthquakes observed in the localities.

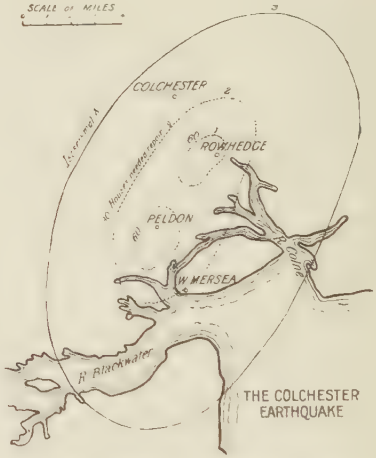

FIG. 70.—THE COLCHESTER TWIN EARTHQUAKE, 1885.

(After C. Davison.)

2. *Dislocation quakes* are very severe, and are felt over areas as far apart as the poles. A distinct epicentrum is generally wanting, and the centrum may be as much as 17 miles deep. Many earth-shakers show no sign of surface dislocation, but are classed as dislocation quakes because their effects are of that order. The Cutch earthquake in 1819 was accompanied by a fault 10 feet high, which ran for miles. Other earthquakes with visible faults were the Mino-Awari of 1891; the Bengal-Assam of 1897; the Cook Strait (New Zealand) of 1855; the San Francisco and Valparaiso quakes; and, more recently, that of Messina.

Dr. Davison applies the title 'twin earthquakes' to those in which there are two foci and two shocks, both due to a single movement. The earthquakes of Naples (1857) and Messina (1894), and those of Colchester (1885) and Derby (1903-04), were 'twin earthquakes.'

In the British Isles small dislocation quakes are of frequent occurrence along well-known fault-lines, and tend to show that earth building still goes on. Thus, between 1889 and 1904 at least 160 were recorded by delicate self-registering instruments (seismographs), the majority having arisen where movements have repeatedly occurred—*e.g.*, the Great Glen, the Lake District, and the Highlands.

The Colchester earthquake was comparatively severe, for the shock was felt over 50,000 square miles, and 12,000 to 13,000 buildings were destroyed. It possessed two epicentra, situated 4 miles apart, the isoseismals being elongated in the direction of the line joining them; hence Dr. Davison maintains that the centra are portions of one and the same fault, which has moved in opposite directions at its two extremities.

It might be supposed that regions devastated by volcanoes and earthquakes would be shunned, but history shows that this is far from being the case: Lisbon, Kingston (Jamaica), Tokio, San Francisco, and Messina, have risen again on their ruins; a populous district surrounds the buried cities of Pompeii and Herculaneum. Some of the destroyed cities are on great commercial highways, with good harbours in fertile and productive districts, so that people return to them again; in other cases the population is too dense to admit of removal. Moreover, man's memory is short; after a violent eruption or earthquake a period of comparative quiet usually follows, giving rise to a sense of false security. Volcanoes are safety-valves so long as their vents are kept open; if stopped up, the lavas and gases will struggle to escape until an outburst relieves the strain.

Eruptions, unless overwhelmingly destructive, like that which destroyed St. Pierre, will not drive away a settled population, and the damage done is relatively small—earthquakes are far more destructive in their effects. The torrents of mud formed by rivers sweeping along the loose ashes of Vesuvius after an eruption are more feared than the rain of ashes itself or the lava streams. The slopes of many volcanoes are clothed with vineyard and forest, and studded with villages, because lavas and ashes yield a fruitful soil which in some sense compensates the peasantry whose lands have been invaded.

Earthquakes shake down avalanches* and loose rocks, which may hold up the drainage and form lakes. Surface cracks and chasms appear, and often become permanent watercourses. Springs, brooks, and lakes are affected, some of the latter having dried up; others, again, have come into existence.

Fig. 71.—Destruction of St. Pierre, Martinique.

In Japan special care is taken to make houses earthquake proof. The steel-frame buildings of San Francisco withstood the shock infinitely better than the masonry or brick buildings, and those founded on rock better than those on loose soils. Similarly, when Port Royal, Jamaica, was destroyed in 1692, the houses built on limestone suffered least.

The greatest dangers arise either from sea waves, or from fire and destruction of the water-mains. The Japanese carry their lights out of doors when severe shocks are felt. A great sea wave, propagated by a suboceanic earthquake, often reaches a coastline already shattered by the earthquake, and completes its destruction. This happened at Lisbon in 1755, and at Messina and Reggio in 1908.

CHAPTER VII.

Destruction of the Land.

All deposits forming the dry land are exposed to unceasing attack by the agents of destruction, which will eventually reduce them to sea-level if elevating forces cease to operate. This result is brought about by a process known as **erosion** or **denudation,** consisting of: (*a*) *weathering*, or breaking up piecemeal of the general surface of the land; (*b*) *transportation*, the carrying away of the weathered material; and (*c*) *corrasion*, the filing away of rocks, river and glacier-beds, during transportation of rock waste.

The rate and amount of destruction is controlled by certain conditions; thus, erosion is greater on the steeper slopes, because with the aid of

* Professor Tarr attributes the recent advance of Alaskan glaciers to snow avalanches shaken off the hills by earthquakes some years ago.

gravity transportation is easier, and this, by exposing bare faces to attack, allows weathering to go on more quickly. Again, softer rocks will in general be more easily destroyed than hard rocks; but erosion in a damp climate will be very different from that in a dry climate, since it involves differences in both rainfall, temperature, and vegetation. The greater the temperature range and amount of rainfall, the greater the erosion.

Weathering and certain forms of transport which are almost inseparable, may be conveniently discussed at this stage. Weathering agents are of atmospheric or organic origin; their effects may be classed as (1) *chemical*—performed chiefly by dews, rain, and decaying vegetation; and (2) *mechanical*—performed chiefly by temperature changes, frost, rain and wind, vegetation and animals.

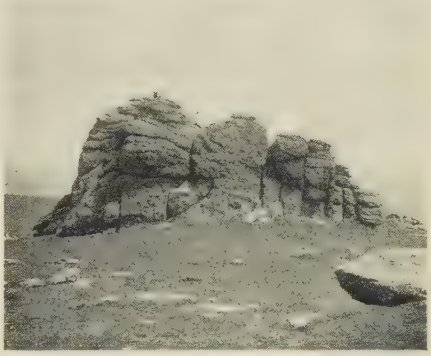

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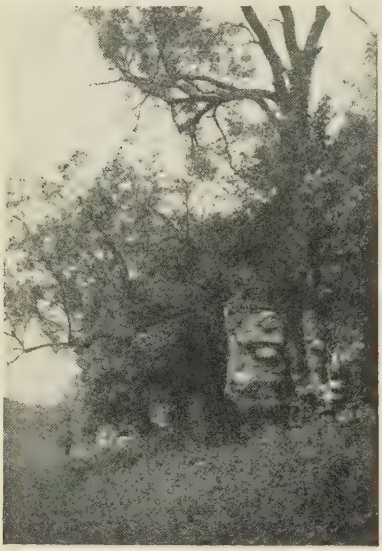
FIG. 72. — HEY TOR, DARTMOOR.
Weathering of well-jointed granite.

Weathering in a Temperate Climate. — Atmospheric waters can dissolve small quantities of most substances—a power increased by the carbonic acid which they absorb from the atmosphere and the soil; and since practically all known rocks contain in their pores a certain amount of water, it must give rise to considerable changes. Water attacks the rocks as dew which can reach the under surface of overhanging ledges, or as mist and rain. Freely traversing the more porous rocks, it removes their soluble cements, or attacks the mineral crystals until the fabric is loosened. It attacks in particular edges and corners, where two or three sides are exposed simultaneously, so that they become rounded off like those of a lump of sugar dissolving in tea. In this manner natural fissures, such as bedding planes and joints, are widened, and the rectangular blocks of rock become rounded at their edges and corners (Fig. 72). The felspars of granites are disintegrated and removed, leaving the loosened quartz and other resistant minerals to fall to the ground unhurt.

Water containing carbonic acid gas readily dissolves limestone, especially along joints and stratification planes (p. 38), which it rapidly

widens. *Chemical weathering* thus not only removes some of the rock by solution, but also loosens its fabric, so that it yields more readily to those agents which act in a *mechanical* way.

Rocks expand when heated and contract when cooled, and the individual crystals of which the rock is built up and which lie in all directions are similarly affected, tending to destroy the coherence of the rock—an effect commoner in desert than temperate regions. Of more importance is the freezing of water in crevices, where it expands with almost irresistible force, widening joints and fissures, and loosening blocks of stone, until gravitation causes them to fall to lower levels. In the same way the thickening roots of trees and bushes, thrust into every spot affording holding ground or sustenance, act as levers to wedge the rocks apart. Even in towns tree-roots may be seen causing walls or footpaths to bulge and break. Vegetation has also a certain chemical action. Mosses, lichens and so forth, hold water against the rock until cavities are worn beneath the covering of vegetation which supplies corrosive organic acids to the water.



B. Smith.

FIG. 73.—TREE GROWING IN JOINT IN LIMESTONE, VALE OF CLWYD.

(See Fig. 49.)

Burrowing animals, like badgers, moles, rabbits, rats, and earth-worms, undermine the surface, turn it over, and expose the looser earth fragments, so that even grass-covered surfaces may suffer slow weathering and destruction.

The combined effects of weathering, structure of the rocks, and gravity, sometimes give rise to rock-falls and landslips. If the weakened rocks are inclined towards the face of a cliff, they may fall of their own weight; or percolating waters may saturate a porous rock (like sandstone), resting on a nearly impervious clay, and render it so heavy that large masses slide outwards and downwards, slipping on the lubricated clay surface. The famous Axmouth landslip of 1839 was caused in this manner, and it is matched on a smaller scale all round the sea-

coast, wherever pervious beds of rock (p. 75) rest upon impervious ones with a seaward dip.

The wind is sometimes sufficient to detach loosened pieces of rock and small grains from exposed surfaces, but is most effective as a weathering agent when it bombards the rocks with the sand and stones it has been whirling along. In desert regions this sand-blast is strikingly manifest.

Raindrops beating upon soft rocks cause the surface to be broken up and particles to be removed by little runnels of water. After a short

L. J. Wills.

FIG. 74.—EARTH PILLARS FORMED FROM BOULDER CLAY IN THE TYROL.
Similar pillars are formed in the boulder clay and Old Red Sandstone conglomerate of Fochabers, Elgin.

shower rainprints may be seen on a layer of mud, each showing a ridge cast up by the impact. The effect of rain is greatest on the steepest slopes and when unequally distributed—*i.e.*, when there are alternating wet and dry periods. In temperate climates much more débris is carried to lower levels by thunderstorms or cloud-bursts after drought than by steady, chronic rains. Large stones often serve as protection against rain-drops and runnels; hence in soft deposits containing stones—such

as boulder clay—a series of pillars may be formed, each of which is capped by a large protective stone or patch of stones (Fig. 74). Similarly, soft rocks tend to be eroded, leaving hard rocks behind (*e.g.*, the 'grey-weathers' of Wiltshire and Dorsetshire).

Deposits Formed by Weathering—*Soil.*—If the transporting agents (wind, rain, etc.) are unable to carry away the finer particles of rock-waste, a soil, which is the excess of weathered material, is left behind. In character the soil depends upon its constituents. Plants, by their decay, supply organic matter, which, together with bacterial action, gives rise to dark fertile vegetable soil called 'humus.' Animals also furnish organic matter which is the source of most of the carbonic acid taken up by subterranean waters.

FIG. 75.—SOIL-CREEP CAUSING ROCKS TO BEND IN DIRECTION OF MOVEMENT. (After Jukes.)

In places soil increases in thickness, and it is often added to by dust, but, on the whole, it is being constantly stirred up and removed from above by burrowing animals,* wind, and rain, and is constantly replenished from below, which accounts for ancient stone implements being found at the surface alongside present-day waste. The soil passes downwards into subsoil—broken rock penetrated by rootlets from above—and then into solid rock. Soils on flat lands are not so easily removed as those on slopes, and may become rich in organic matter through growth of dense and often marshy vegetation. Thus, rich dark loams are formed like those of the *regur*, or black cotton soil, of India; the *tchernozom*, or black earth, of Russia; the soils of the American prairies and savanas, the fenlands of England, and the drained peat-mosses of Scotland and Ireland.

The sheet of waste, aided by gravity, water, burrowing animals, and so on, creeps slowly down hill-sides to the valleys, causing trees, as it moves, to lean outwards down the slopes, and frequently affecting the underlying rocks in a similar manner.

* Darwin has shown that mould is largely due to earth-worms.

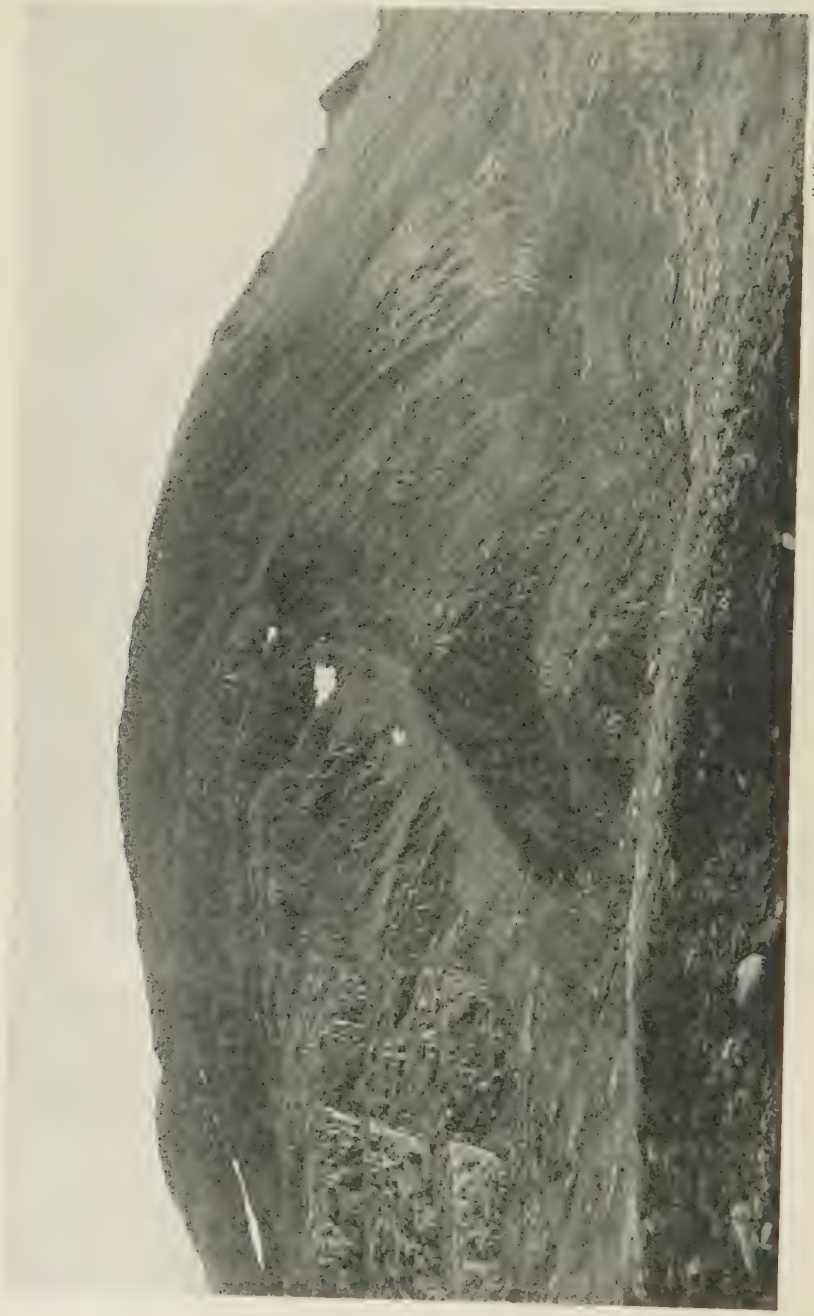
Scree, Talus, and Cliff Débris.—At the bases of steep crags or valley sides (especially where there are gullies) there are rough accumulations of rock, composed largely of angular fragments split off from above by weathering. The blocks lie at the angle of rest—about 40°—but the slope is steeper when the blocks are large. Like the soil, scree material moves slowly downhill, aided by torrential action and the daily contraction and expansion of the blocks with changes of temperature (Fig. 77).

Blown Sand.—When winds are blowing from a large supply of sand, such as the dry foreshore near the sea, or a desert area, grains will be picked up and whirled along. (Pine-trees near the cliff edge at Boscombe are stripped of their bark and branches by the sand-blast on their seaward sides.) The coarsest grains are rolled along the ground, those somewhat finer progress with a hopping motion, and the finest are blown bodily into the air. Wind-blown sands are said to be 'Æolian,' and invariably have spherical grains of various sizes; they thus differ from water-formed sands, which are usually angular and sorted into uniform grades.

H. Speyer.

Fig. 76.—Talus Slopes beneath a Frost-Riven and Serrated Ridge, Crib-Goch, Snowdon, North Wales.

If the weight of sand becomes greater than the wind can carry, a certain amount will be dropped and a *dune* commenced. Frequently, however, an obstacle arrests the sand and forms a small bank, over which the wind blows, forming on the shady side an eddy, which tosses up the lighter grains into the air. The forward movement of the coarser grains is to some extent arrested by the eddy, so that a nearly permanent structure is built up, with a gentle slope to windward and a steep slope to leeward, where the sand is almost at the angle of rest (about 30°), the height of the dune being about one-third the length. Owing to slight alterations in the direction and strength of the wind, and therefore also the size of the grains, the sands are highly false-bedded, and small eddies



H.M. Geological Survey.

FIG. 77.—DISPERSAL OF TALUS BY TORRENTIAL ACTION, BEINN LIATH MHÒR, ROSS-SHIRE.

formed under certain conditions of wind-velocity on the surfaces of the dunes give rise to ripple-marks.

Dunes sometimes march forward during high winds—the coarse particles rolling over the crest to the leeward slope—and encroach upon the country, burying houses, churches, trees, and fields in their progress. A single advancing dune (*barchan*) is crescent-shaped in plan, with the horns pointing in the direction of movement. Dunes are extremely common round the English coast, often obstructing the drainage (Fig. 172), but they are also found inland on the outcrops of sandstones, such as that of Sherwood Forest, or piled up on sandy river-flats.

H.M. Geological Survey.

Fig. 78.—Blown Sands with False Bedding, Newquay, Cornwall.

The various products of weathering are eventually reduced to a fine state, either before or after they have been removed by streams (Chap. IX.). Their final resting-place is the sea, where they form new sedimentary rocks.

Weathering in an Arid Climate.—In deserts, where the rainfall is small and the sun's heat excessive, weathering is mainly mechanical, although dews acting in the shade are responsible for chemical rotting of rock. Bare rock is exposed to the fierce solar heat, and the rapid radiation allows of a diurnal range of perhaps 130° F., which splits up both rocks and crystals to form heaps of scree material of all sizes. Wind

rapidly whirls away the finer parts to form sand and dunes, and the occasional severe thunderstorms sweep the larger fragments to the valley-bottoms. Sands are blown away from stones, leaving pebble deserts; pebbles are smoothed by the sand-blast, and have their sides flattened and polished; cliffs are undercut until the tops come toppling down in ruins, for more sand is blown against the bottom than the top; hard rocks are glazed and polished and cut into grooves along structural planes or soft layers (Fig. 79). When the rocks of Mount Sorrel, Charnwood Forest, were stripped of their covering of marl during quarrying operations, the hard granite was found to be grooved and polished by the sand-blast of the ancient Triassic desert. Coarse screes and blown sands are also found resting against the granites.

Fig. 79.—The Great Sphinx, Gizeh.
The softer layers of the stone are hollowed out by the sand-blasts.

Tropical Regions.—Heat and moisture encourage a profuse vegetation, which aids weathering by increasing the solvent power of percolating water, but otherwise acts as a check to weathering by screening the ground from raindrops and holding up finely comminuted rock amidst roots and fallen leaves, thus clogging the transportation of material. The deep soil also stops the work of frost, and acts as a reservoir from which the water is let out slowly and equally.

Polar Regions.—Weathering on the low ground is largely checked by the mantle of ice and snow, but the high peaks suffer both from frost and temperature changes—that is to say, the action is mostly mechanical, and the work of transport and corrasion is relegated to glaciers (Chap. XII.).

Marine Erosion.—The destruction of the land by the sea takes place laterally. Atmospheric erosion might be compared to the action of a carpenter taking shavings from the surface of a plank; marine erosion to his cutting pieces off the edges (Chap. XIV.).

In early times Britain was covered with forests like those of Arden and the Weald, but they have nearly all been removed and replaced by bracken, heath, pasture, and bog on the uplands, and meadow and arable land on the lowlands. The removal of the forests affected the climate and surface soils; it exposed to sun and wind districts which had been kept cool and damp beneath the shade of trees, or which were protected from tempests. Soil previously held upon the hill-sides was washed rapidly away by rains and the bare rock revealed.

Agriculture sometimes aids the atmospheric agents, for by drainage of the soil evaporation is lessened and the rainfall diminished, the heat of the soil increases, and also does the general temperature. In districts where trees have been replanted on a large scale, the climate has become moister. On the hill-slopes the plough, aided by gravity, tends to move soil downhill. Sand dunes thoughtlessly stripped of their protective covering of grasses, etc., have been allowed to move again and devastate productive land. The system of hedge-rows, walls, and banks in the British Isles to a certain extent neutralizes the destructive effect by holding up rainwash, creeping soil, or wind-blown sand. In some cases rainwash accumulates to a depth of many feet on the uphill side of a hedge-row, and blown sand may be banked up to the hedge-top (Fig. 80). The distribution of the agricultural population depends largely upon situation and soil. On the steeper slopes and bleak hill-tops soil is thin and only suitable for herbage; it is thickest in the lowlands and on the gentler slopes of hills and valleys, especially on gravelly, sandy, and loamy

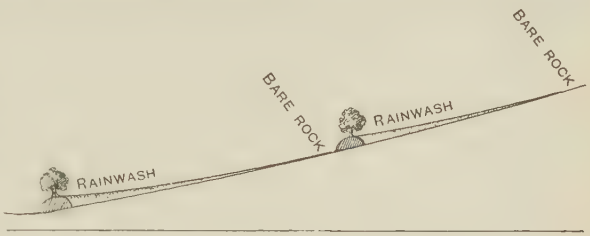


FIG. 80.—RAINWASH HELD UP BY HEDGES AND BANKS.

FIG. 81.—LYNCHETS, ISLE OF PURBECK. (After H. B. Woodward.)

areas. In such spots the population is denser than elsewhere. Chalk has such a thin soil that in times past husbandmen prevented it from being washed away by forming terraces, called 'lynchets,' on the hill-sides (Fig. 81).

In London and other large cities the rainfall is diverted into sewers, and the surface soil is a mixture of mould, gravel, clay, rubbish, and débris of ancient buildings. Much of this has been turned over and over again, so that it comprises an accumulation of brickbats, fragments of crockery, and what not, mingled with relics of soil and subsoil. In some places it has accumulated at the rate of 6 inches to 1 foot in a century. Such soil is called 'made ground,' and some is of very ancient date, preserving relics of past historical events. At the Bank of England it is 22 feet thick.

CHAPTER VIII.

Topography and Maps.

Topography is a detailed description of a particular place or tract of land, and a topographic map is one upon which as much information as possible is inserted in such a manner that it can be interpreted by the inquirer. **A full and accurate topography** will show (1) the structure of the surface of the ground, its division into mountain and valley, plain and plateau ; (2) the distribution of land and sea, the positions of lakes, streams, and rivers ; (3) the works of man, railways, bridges, roads, hedges, walls, buildings, and so on. With such a map for a basis, further information, such as the distribution of animals and plants, geological or economic boundaries, may be added to furnish maps for special purposes.

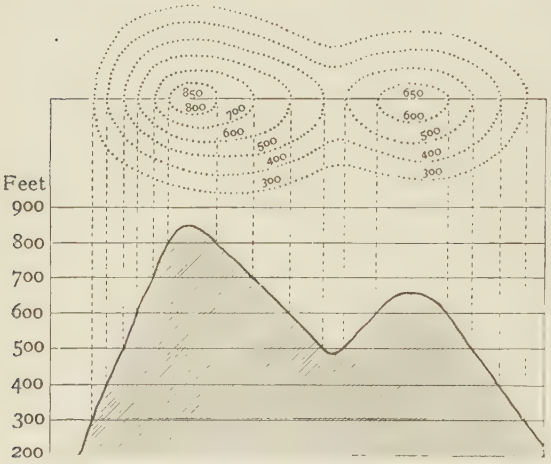


Fig. 82.—Contour Map of two Peaks. Vertical Scale much exaggerated.

Relief.—It is an easy matter to represent rivers, lakes, woods, or buildings on a flat sheet of paper, but it is difficult to show the elevations and depressions of the land, the forms of the hill-slopes, and their steepness. These can only be represented diagrammatically. The prettiest and most effective method is by hill-shading, in which horizontal or vertical lines, known as *hachures*, are employed according to a fixed scale of shade. Vertical hachures follow the direction of the steepest slopes, and horizontal hachures are everywhere at right angles to such lines. The lines are crowded together upon the steepest slopes, so that the shade is nearly black, and widened out on the flat until the shade is perfectly white. The objection to them is that, when printed in black, they obscure other important details on the map, and

for this reason the old, beautiful, black hill-shaded maps of the Ordnance Survey are no longer issued, but replaced by maps in which brown vertical hachures are combined with red contour-lines, giving the nearest approach to an accurate scientific expression of surface features.

Contours.—Contours are imaginary lines produced by the intersection of horizontal planes with the surface of the ground. They connect points at the same height above sea-level (Fig. 82). If, for example, the country were lowered 300 feet, the present 300-foot contour would become the new shore-line. A contoured map is therefore superior to a hill-shaded map, because it represents, not only the absolute height of any point above sea-level, but also its height above or below any other point. The regular distance between any two contour lines is called the *contour interval*; upon the 1-inch Ordnance maps this is usually 100 feet up to heights of 1,000 feet, above which the interval is increased to 250 or 500 feet. Contours also show the shape of a hill and the exact degree of slope; where the hill is steep, the lines are naturally crowded together; where gentle, they are far apart. In some maps—*e.g.*, motor and cycle maps—the intervals between the contours are shaded with different tints of colour—an excellent plan, provided that the contour intervals are small, and the colour changes not too abrupt. When the surface features are low, contours fail to indicate the hills and valleys at a glance; hachures or colour tints are then especially needed.

Example for Study.—The map, Fig. 83 (reproduced by permission from the 1-inch Ordnance Survey map, Sheet 29), has been chosen to illustrate the expression of surface relief by means of contour lines and hill-shading,* and should be carefully studied in conjunction with the view given on p. 71 (Fig. 84), and the description of the lakes in Chapter XIII.

The following points may now be noted:

1. The combination of contour lines and hachures produces an artistic effect, suggesting that the district has been carved and sculptured like a model landscape.

2. The high land from which it has been sculptured had once an elevation above sea-level of over 2,500 feet, for the taller summits average that height.

3. Buttermere (330 feet) drains into Crummock Water (321 feet) by a stream which falls only 9 feet in three-quarters of a mile; therefore the tract of land separating the lakes must be exceedingly flat. This flatness is shown by the

* In the map issued to the public the contours are in red; the hill-shading, brown; lakes and streams, blue; woods, green; roads, orange; lettering, etc., black.

Reproduced from the Ordnance Survey Map with the sanction of the Controller of H.M. Stationery Office.

FIG. 83.—TOPOGRAPHIC MAP OF THE BUTTERMERE DISTRICT, CUMBERLAND.

C, Delta of Comb Beck.
D, Delta of Sail Beck which enters Crummock Water south of Wood Ho.
H, Delta of Hassness How Beck.
O, Outlet of Crummock Water.
P, Delta of Park Beck.
R, Delta of Rannerdale Beck.
S, Delta of Scale Beck.
W, Delta (combined) of Gatesgarth and Warnscale Becks.

See also Figs. 84 and 180, and p. 145.

G. P. Abraham.

FIG. 84.—BIRD'S-EYE VIEW OF BUTTERMERE AND CRUMMOCK WATER (Loweswater in distance), SEPARATED BY A FLAT BELT OF ALLUVIUM (Sail Beck Delta). From the Crag east of Warnscale Bottom.

(See also Figs. 83 and 180, and p. 145.)

absence of hachures upon the deltas, except where they descend rather steeply, as at S.

4. Similarly, the tops of the hills, by the same absence of shading, are shown to be flattened.

5. The 400-foot contour (the lowest) completely encloses the lakes, except at the outlet in the north. If the country were to be submerged to this extent, the sea would enter and convert the valley into an estuary—mean tide-level being the present 400-foot contour line.

6. The contour interval is 100 feet up to 1,000 feet, 250 feet to 2,000 feet, above which it is 500 feet.

The contour lines bend *into* the depressions, and make **V**-shaped prolongations up the steeper valleys, such as that of Sail Beck and Warnscale Bottom ; they also swing *outwards* round the hill-spurs. Upon the steeper slopes—Burtness Wood Rannerdale Knotts, and Mellbreak—they are crowded together. The slopes appear to be more gentle at the summits of the hills ; this is partly the case, but the effect upon the map is increased by the wider contour intervals above 1,000 feet. In reality the middle slopes of the hills are the steepest (*cf.* the profile of Mellbreak, Fig. 84), as would be apparent if the contour interval were 100 feet throughout. Here and there the contours follow lines of crags, as on Snockrigg and Robinson. The summits of the hills are marked by closed contour lines—*e.g.*, High Stile, Starling Dodd, and Grassmoor. Closed contour lines would also encircle a basin-shaped hollow with no outlet.

7. Some of the smaller torrents make very small notches upon the hill-sides.

8. Roads and footpaths take advantage of the valleys and low gaps between the hills (Scarth Gap Pass and Newlands). The main road upon the east side of the lakes traverses delta-flats and lower slopes throughout most of its course ; at Hause Point, however, it is cut in rock. The habitable sites are mostly on the deltas where the streams emerge from their valleys.

Study of Maps.—The importance of studying good maps cannot be too strongly urged ; every opportunity should be taken of reading and reproducing portions of them. When spending a holiday anywhere, a map should be one's constant guide and companion : with its aid the face of the country will be read and interpreted, and in days to come readily called to mind. The maps of the Ordnance Survey, on the scale of 1 mile to the inch, are excellent,* but if this scale is too large, smaller maps on the scale of 2 or 4 inches to the mile will be found useful, but less detailed. Students of geography, especially physical geography, should be continually asking themselves and attempting to answer questions like the following :

Why is the railway on an embankment here and in a cutting there ? If it is necessary to tunnel, why at this particular spot ? Why do most of the railway-

* The recent colour-printed maps of H.M. Geological Survey (issued at 1s. 6d.) have geological boundaries and colours printed upon the 1-inch Ordnance maps, and are therefore most suitable for the study of physical geography.

lines run along valleys close to the rivers, whilst the main roads keep to the valley-sides ? This road has been lately made good, and that allowed to become a mere track—is there any reason for it ? Why does one road zigzag, another run straight ahead ? What is the reason for the large size and tremendous energy of one town and the quiet sleepiness of another ? Has the position, mineral or agricultural wealth, of the neighbourhood anything to do with it ? Here there are many villages in clusters or lines, there a village is a rarity—what is the reason ? In this district woods are plentiful, in that few trees are seen—is it because the soil or climate is different, or for some other cause ?

The above are very few of the questions maps will suggest to us ; some will be easily answered, others will require more study, but most of them will depend for their solution upon knowledge of the physical geography of the districts. Railways, for example, find the easiest gradients on the river flats, where embankments raise them above flood-level. Roads generally avoid the same flats in order to escape the floods.

Fig. 85.—Sketch and Section illustrating the Influence of Rocks and Rock Structure upon Surface Features.

Sites of villages are frequently determined by water-supply, which may often be best obtained along the line of outcrop of a particular bed of rock.

Earth-Sculpture.—Apart from the works of man, the surface features of a district are due to two main causes : (1) To *uplift* of the rocks ; (2) to the *sculpturing* of the uplifted rocks by the agents of denudation. Certain simple topographic forms are due to the first of these causes. A general uplift of the sea bed might produce a plain or plateau ; an earth-wave, a mountain and valley ; but before long, running waters, sun, wind, and so on, would set to work and cut up the plateau into isolated hills, separated by deep valleys, and the single earth-wave into a watershed and valley with a complex drainage system. At this stage the composition and structure of the rocks would begin to influence the topographic forms. Hard rocks would project ; soft rocks form the gentler slopes, for the weaker, unless protected by the stronger, ever goes to the wall.

The above diagrammatic sketch and section shows how rocks may have a considerable effect upon surface features when they have been for a long time exposed to Nature's sculpturing tools.

CHAPTER IX.

Drainage of the Land.

UNDERGROUND DRAINAGE.

LAND water circulates either upon the surface, in brooks, rivers, and lakes, or beneath the surface, when it may act as a feeder to rivers or lakes, and is known as 'ground-water.'

By far the greater part of the ground-water is derived from rainfall, but a small amount probably comes from the sea and from the rocks. The commoner sources are as follows :

The atmosphere: (1) Directly, by precipitation as rain, hail, or snow, and condensation as dew; (2) indirectly, by leakage from lakes and rivers.

The ocean: (1) By percolating inland; (2) by inclusion in rock beds which have been uplifted from the sea in such a manner that the waters could not drain completely away.

From the rocks of the earth's crust, by chemical change, heat, or pressure.

Atmospheric Waters.—Water falling upon the land is disposed of in several ways. A certain amount evaporates from the surfaces of pools, from vegetation, or soil and rock surfaces. Footpaths are quickly dried after rain; snow slowly disappears by evaporation; and dew vanishes with the morning sun. Vegetation absorbs some of the water, whilst the remainder either runs directly off the surface into the rivers, and so to the sea, or is taken up by the soils and rocks.

Of these methods of disposal, the last two are undoubtedly the most important. If the rainfall is extremely heavy, more will probably run off the surface than will be absorbed, but, as a rule, this is not the case. The quantity absorbed naturally differs with the nature of the rock, the amount of vegetation clothing it, and the climatic conditions. On tracts like the outcrop of the Bunter Pebble Beds and Sandstone of Central England, very little water runs off the surface, the greater part is swallowed up; similarly the porous chalk sucks up most of the moisture shed upon it. Gently falling rain or slowly melting snow will readily sink in the ground, but a frost followed by rain and a sudden thaw will result in the water being rapidly swilled off the still frozen ground to swell the volume of the rivers.

Reservoirs.—Nearly every rock is porous to a certain extent, but some much more than others. A well dug in almost any kind of rock will collect ground-water, even if a permanent spring is not struck. An 'impervious' rock is one through which water penetrates with difficulty or which successfully holds up most of the moving water. Clays are perhaps the most impervious beds, because of the absence of joints and stratification or lamination planes; shales are also fairly impervious, whilst sandstones, limestones, and granites (the latter mainly through joints), are often extremely pervious. Water-bearing beds are called 'underground reservoirs,' but they are totally unlike ordinary surface reservoirs. The water is contained in (1) natural pores in the rock—bedding, cleavage, and lamination planes; (2) pores made by solution and removal of material, such as rock-cements; (3) channels and cavities due to solution or mechanical wear; (4) fractures—joints and faults.

The depth to which water sinks in the earth's crust varies, but perhaps never reaches more than 5 to 6 miles, for at this depth the pressure of the overlying rocks would be so great that ordinary pores and cracks would probably be closed. Although some shallow mines are quite dry, water has been met with at the greatest depths ever reached by man in boring. Immense springs of hot water were struck when the Simplon Tunnel was bored, the mountain at that point towering several thousand feet above.

Rocks with natural pores—*e.g.*, loosely consolidated sandstones—come first in the list of water-bearing beds, and those with solution cavities and channels perhaps second.

Solution.—Rock salt and gypsum, the buried deposits of salt lakes or inland seas of past ages, are often removed by solution, just as similar salt is extracted in Cheshire at the present day by adding water and then pumping out the brine. In such districts removal of the salts leads to collapse and the formation of hollow depressions at the surface, and similar but more complex results occur in regions of calcareous rock—limestone, chalk, or dolomite.

In the district north-east of Ingleton, West Yorkshire, the Mountain (Carboniferous) Limestone, with strong jointing, rests upon nearly impervious slaty rocks, and is partly covered by shales and sandstones (Fig. 86). Water from the sandstones, holding carbonic acid gas from the atmosphere, runs off the shales on to the limestone. Coming to a joint it trickles down, enlarging it by solution, and making it cylindrical by whirling stones round and round as they fall. It then passes from one bedding-plane to another, down joint after joint, until it reaches the impervious

slates below, and flows along their gently inclined upper surface. In course of time the edge of the shale above the limestone is fringed with these 'swallow-holes,' or 'swallets,' and as the shales are cut back by weathering fresh ones may be produced as new joints are exposed.

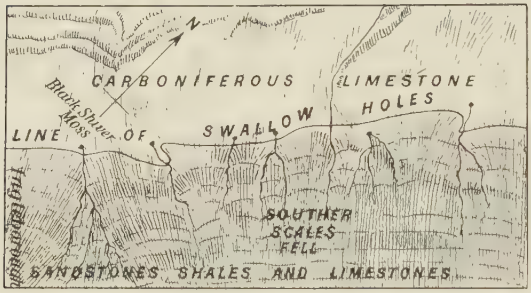


FIG. 86.—STREAMS DISAPPEARING IN SWALLOW-HOLES, N.E. OF INGLEBOROUGH, YORKS.

Gaping Ghyll, above the Ingleborough Cave, is 360 feet deep, and Elden Hole, in the Peak, quite 300. In width 'swallets' may measure as much as ½ mile, but these, like the Hellan Pot, Ribblesdale, are caused by collapse of cavern roofs.

Caverns.—Continual widening of joints and stratification planes, especially where they meet, and coalescence of the water channels, results in the formation of caves whose sides are often defined by joint faces. If one stratum is more soluble than another, the cavern may be as high as the bed is thick. A passage in the Mammoth Cave of Kentucky is 8 miles long, and some are 75 feet high and 50 to 150 feet broad. The caves of the Peak District, Derbyshire, are justly celebrated; and there are excellent examples of swallow-holes, caverns, and underground drainage in the Mountain Limestone of the Mendip Hills, which are riddled through and through. Mr. H. E. Balch, in 'The Nether World of the Mendips,' writes as follows:

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FIG. 87.—THE CHEDDAR GORGE.

'Through crevices and cracks, here, there, and everywhere, the percolating waters find their way. Now some crevice is enlarged into a passage; now some weak point in the passage becomes a chamber; and on the water rushes, steadily joining forces and accumulating until on the level of the lower land it finds an outlet and rushes forth a considerable stream. In its headlong course the water again and again leaps down some great

series of potholes, as down some great stairway forming many fine cascades. . . . Along the course of the larger streams huge chambers occur: for the ever eddying water, bearing sand along in its course, eats out the sides of its channel, or, revolving stones in its bed, carves out the pothole by friction. Or some pendent mass of rock has its support undermined and comes crashing into the streamway, only to be broken up and carried away by the ceaseless energy of the stream. . . .'

When weakened, parts of the roof sometimes fall and expose the caverns to the light of day; or the whole course of the subterranean river may be thus unroofed, the fallen blocks perhaps hiding the stream from sight. This process has given rise to magnificent gorges, like that of Ebbor, near Wells, or, more famous still, that of Cheddar (Fig. 87), which the water has now deserted. The largest cave in Ireland, if not in the British Isles, is situated 12 miles east of Mitchelstown, Tipperary. Including all the passages cut in the limestone, it is $1\frac{1}{4}$ miles long, and is remarkable for the right-angled disposition of channels formed along widened joints (Fig. 88).

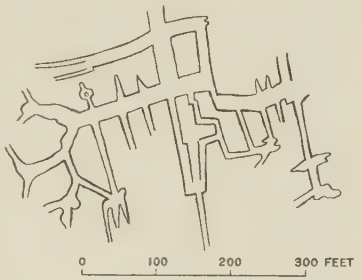

Fig. 88.—Plan of Passages, following Joints, Mitchelstown Cave, Tipperary.

(After A. E. Martel.)

Minerals in Solution.—In the caves beautiful effects are produced by the percolating waters evaporating drop by drop, and depositing the lime they held in solution either as *stalactites* pendent from the roof, or, when the drops fall to the floor, as *stalagmite*, which may grow upwards and unite with the stalactites to form long slender columns of rare beauty (Fig. 89). In a similar way the petrifying springs of such districts distribute a coating of limestone upon objects placed beneath their spray, and sometimes form beds of limestone known as 'tufa' or 'travertine' (Fig. 90).

A tremendous amount of mineral matter is removed in solution by ground-water, and either discharged into the rivers and sea or dissolved from one rock and deposited in the hollow cavities of another rock without coming to the light of day. Frequently it gives rise to mineral and medicinal springs—*e.g.*, the salt waters of Cheltenham, the earthy waters of Bath, and the sulphurous waters of Harrogate. Some of these spring waters are warm or hot, and thus furnish a link with the hot sinter-depositing springs and geysers of volcanic districts.

Destructive Action.—By the rasping action of the sediment the carry, as well as by solution, underground waters aid the processes o denudation in weakening rock structures by removal of loosely con solidated material and widening of joints, resulting in the collapse o cavern roofs or sliding of blocks down hill-sides. Removal of the fine particles causes scree material and soil to creep to the valleys. The

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FIG. 89.—STALACTITE AND STALAGMITE, COX'S CAVE, CHEDDAR.

surfaces of impervious beds are wetted, so that heavily waterlogged beds above slide on the lubricated planes (p. 161).

Springs.—When underground waters find their way to the surface, they issue as a seepage, as springs, or full-grown streams—the determining factors being gravity and hydrostatic pressure. The upper surface of the water in an underground reservoir is called the 'water

table,' and is such that, if a part of it is higher than other parts, there will be from that point a movement of water which tends to level the surface. Rainfall causes the water table to rise, drought depresses it. The diagrams (Fig. 92) illustrating the rise of springs will be easily understood if we remember that there must be a head of water, or a downward flow, and that water will generally take advantage of a line of weakness.

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FIG. 90.—THE DRIPPING WELL, KNARESBOROUGH.

A petrifying spring issuing from Magnesian Limestone.

Artesian Flow.—It often happens that water finds its way downwards until it passes under some rock which offers resistance to its passage to the surface. The resistance may be due to the bed above being impervious, or to friction or other obstruction. The water table is thus prevented from rising to a natural level. If, then, a borehole be sunk through the impervious bed to the water-charged stratum, the water (under a head of pressure) will avail itself of this means of escape and rise in the hole, or even gush out as a jet. Such wells are said to be 'artesian.' A decrease of barometric pressure, by allowing air and gases held in the water to escape, facilitates

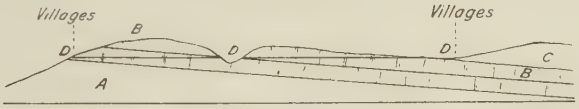

FIG. 91.—DIAGRAMMATIC SECTION OF THE OOLITE PLAIN SOUTH OF LINCOLN. (After W. H. Dalton.)

A, C, clays; B, limestone (oolite); D, D, D, water table.

the flow of some springs and artesian wells. The diagrams (Figs. 93 and 94) show the nature of some artesian systems. The problem of water-supply in relation to man and his environment is dealt with at a later stage.

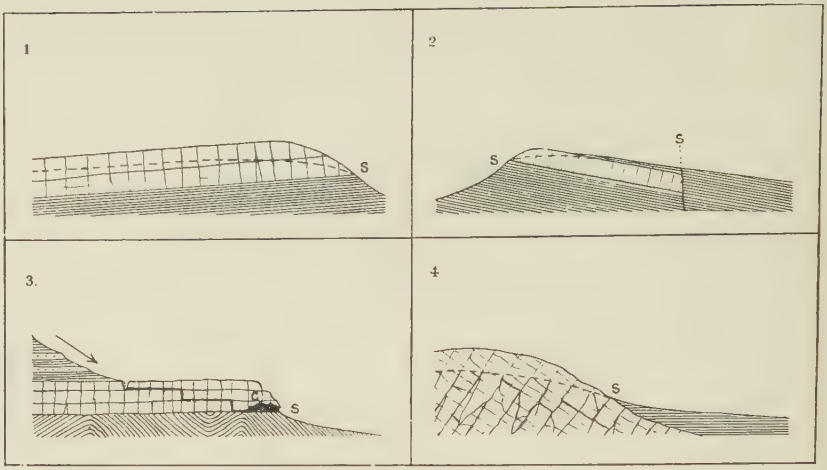

FIG. 92.—SPRINGS.

1, ordinary hillside spring; 2, spring rising through fault-plane and on hillside; 3, full-grown stream issuing from limestone cavern (C); 4, spring issuing from jointed granitic rock. Close shading indicates pervious rocks: open shading indicates impervious rock: S, S, springs; the dotted line is the water table.

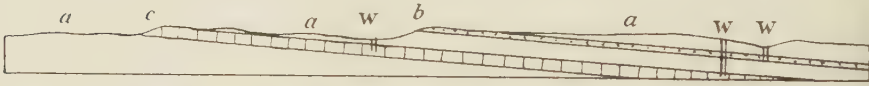

FIG. 93.—AN ARTESIAN SLOPE: A SET OF CONDITIONS COMMONLY FOUND IN THE ENGLISH PLAIN.

a, *a*, *a*, impervious clays; *b*, *c*, pervious beds; W, W, wells.

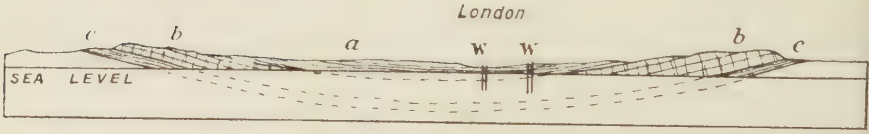

FIG. 94.—AN ARTESIAN BASIN: A SET OF CONDITIONS FOUND IN THE LONDON BASIN.

a, young rocks of the London Basin; *b*, chalk; *c*, gault (clay); W, W, wells

SURFACE DRAINAGE.

Drainage of the land surface is accomplished by rivers and streams flowing in valleys. The water, for the most part, is derived from the atmosphere, some being the direct run-off of rain or melting snow, whilst that which keeps up the permanent flow of rivers is largely ground-water or the surplus stores of lakes; snowfields and glaciers also contribute to the supply. In regions of average rainfall rivers rise in the high lands and flow towards the sea, ever growing in size by the addition of tributary waters, but in deserts they frequently sink from sight in the thirsty sands, or feed the waters of an inland lake which has no outlet.

Tributary streams in a normal well-developed river system meet the main river on the level, neither too high nor too low, and the same is true of the side valleys with respect to the main valley. In certain cases, however, this conformity between rivers and tributaries is wanting, one valley enters another at a high level, and its stream cascades down to the main stream. *Such an arrangement is abnormal*, and may often be traced to interference with the drainage.

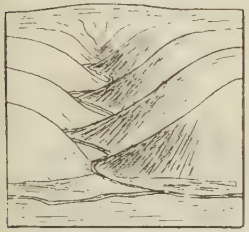

FIG. 95.—NORMAL JUNCTION OF STREAM AND TRIBUTARY.

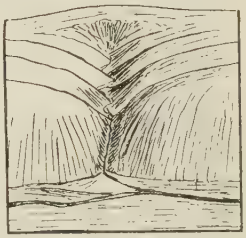

FIG. 96.—ABNORMAL JUNCTION OF STREAM AND TRIBUTARY.

The Transporting Power of Water.—The energy of running water is expended in two ways: (1) In transporting rock waste; (2) in wearing away, or 'corrading,' its bed.

Careful study of the behaviour of rivers has revealed the following facts, which may almost be taken as axioms:

The greater the slope and the quantity of water, the greater the energy of the stream. If there is more energy than is required to carry its load of rock waste, the river will use this waste as a tool with which to scrape, file away, or 'corrade' its bed, downwards rather than sideways. Should the energy be just sufficient to carry the load, the river can only corrade sideways (attack its banks). If the load is too great, the river drops the surplus and carries the remainder. With the same amount of energy the stream can carry a greater load of fine sediment than of coarse, because it is more buoyant.

Base Level.—When a river reaches the sea, its flow is checked, and at the head there is little or no water. Thus there are two points, one at each end, at which the river does no work. Somewhere between them there is another point where corrasion is greatest, hence the bed of the river will form a curve, known as the 'curve of river erosion' (which is steepest near the head) between the hill-tops and the sea. When a river has cut down to the level of this curve, it is said to have reached its '*base-line of erosion.*' As the watershed is gradually lowered by weathering, the base line of erosion becomes a flatter and flatter curve, which, however, can never fall below sea-level. The latter is therefore called *base-level.*

H.M. Geological Survey.

FIG. 97.—SHOWING HUGE BOULDERS IN BED OF RIVER, ROSS-SHIRE.

The Work of a river is that of erosion, transport, and deposit.

We may for convenience divide a normal river into three parts, although in Nature there is no sharp division:

1. The Upper Course—where it is excavating.
2. The Middle Course—where it is making a flood-plain.
3. The Lower Course—where it is depositing.

1. *The Upper Course.*—Instead of flowing off the high ground as a sheet, water collects in little inequalities and makes rills or runnels, which combine with one another to form small becks or torrents. Ground-water also issues by seepage, trickles from springs, or bursts out as full-grown streams. By their own unaided efforts these waters would have little effect; they carry, however, fine sediment—prepared by atmospheric weathering—with which they deeply corrade their channels until they become steep-sided gullies or ravines. As the gullies deepen, new runnels appear on their flanks, and act as feeders to the larger

FIG. 98.—DIAGRAM SHOWING SUCCESSIVE STAGES IN THE LOWERING OF A RIVER'S BASE-LINE OF EROSION TO BASE-LEVEL.

torrents. The rocks become weakened above the point where springs issue, so that they collapse and give rise to semicircular depressions, and when the head of a torrent consists of several uniting runnels, there is usually a similar but larger cup-like hollow known as a 'coombe' (combe, comb, or cwm).* caused by the combination of branching gullies.

The upper waters are choked with rubble freshly fallen from the sides of the gullies, or with boulders which the river can only remove when swollen by rains. Hard rocks make steps over which the water cascades into basins hollowed out by boulders being whirled round and

I. Edna Walter

FIG. 99.—POT HOLES IN A STREAM-BED: AAR VALLEY.

round. At low water the rocks are often seen to be honeycombed with cylindrical 'potholes' formed in a similar way. Thus the hardest rocks are ground into mud by stones, which become ever rounder and smaller as the eddies whirl them about. Lines of weakness, such as joints and bedding-planes, are attacked, and blocks quarried away.

Inequalities in its bed may deflect the stream so that its waters impinge more upon one bank than the other, undercutting it until slices fall headlong into the stream. Thus a young and active torrent can corrade both downwards and to some extent sideways, and is recognized

* When glaciated (see p. 125) these may become 'corries.'

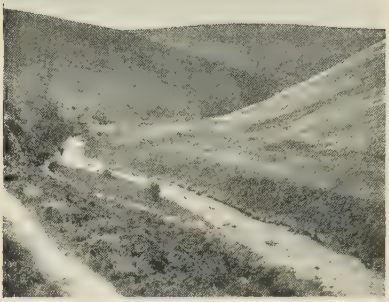

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FIG. 100.—THE DOONE VALLEY, EXMOOR.

Showing overlapping spurs and deposit of alluvium upon the inner part of the river curve.

by its rapid fall (high grade), the general absence of a flood-plain on either side of its steep-sided valley, and by its tumultuous descent (Fig. 117).

2. *The Middle Course.*—On the lower ground most of the stream's energy is absorbed in carrying its load. It ceases to actively deepen its bed, but, since the gradient is now small and the waters are deflected more easily than before, it begins to swing from side to side, widening its valley by lateral corrasion. Suppose the stream has cut a slightly curved ravine, whose walls, wasted away by the atmosphere, are farther apart at the top than at the bottom. The winding course of the stream causes it to undercut the outer walls; hence they will be steeper than the inner walls, which project as spurs into the curves. A view up the valley at this stage will show the spurs overlapping each other from side to side (Fig. 100). As the river continues to cut into the outer bank, the valley floor becomes widened, sediment from upstream is deposited where the current is slack, and fills up to flood-level the inner part of the curve, which at the same time becomes smooth and graceful. The tendency is for the curves to swing outwards and downstream (owing to gravitation), so that the spurs are gradually consumed, and give place to an open flood-plain through which the river winds in serpentine curves or 'meanders' (Fig. 101).

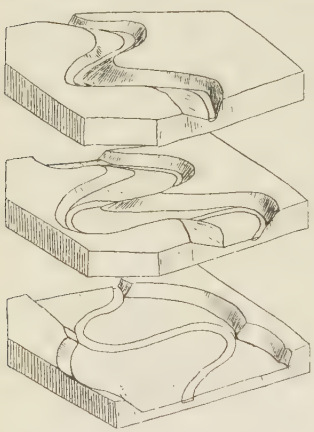

FIG. 101. — DIAGRAM ILLUSTRATING THE FORMATION OF A FLOOD-PLAIN BY A MEANDERING STREAM.

(After W. M. Davis.)

Meanders are best developed when the plain is gently inclined and consists of the finest deposits. A brook wriggles along in small curves, whereas a great river swings grandly round its larger loops.

Flood-plain deposits are known as **alluvium.** At the lowest levels boulders and gravels are deposited upon the rock floor. Sand and gravel is then accumulated to about mean water-level, and the flat surface of the plain is covered by silts and loams, with occasional layers of coarser material laid down during heavy floods. When in flood, the velocity of the current is checked and some of its burden dropped; the coarsest deposits are naturally dropped first, nearest to the channel, hence that part of a flood-plain where the river is flowing is usually higher than the remainder, an

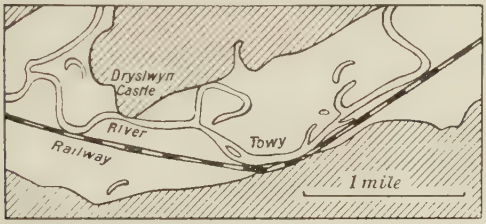

FIG. 102.—OX-BOW LAKES AND MEANDERS OF THE TOWY, CARMARTHENSHIRE.
Alluvium, unshaded.

arrangement which in time makes it an easy matter for the river to find a new channel at a lower level.

When meanders become much exaggerated the necks of the loops may be cut through, when the river deserts its old curved channel for the more direct one thus opened up. The abandoned meander is isolated by river deposits and left as a curved 'ox-bow' lake which in course of time becomes silted up (Fig. 102).

3. *The Lower Course.*—Near sea-level, where the gradient is very low, the river has barely enough power to transport its

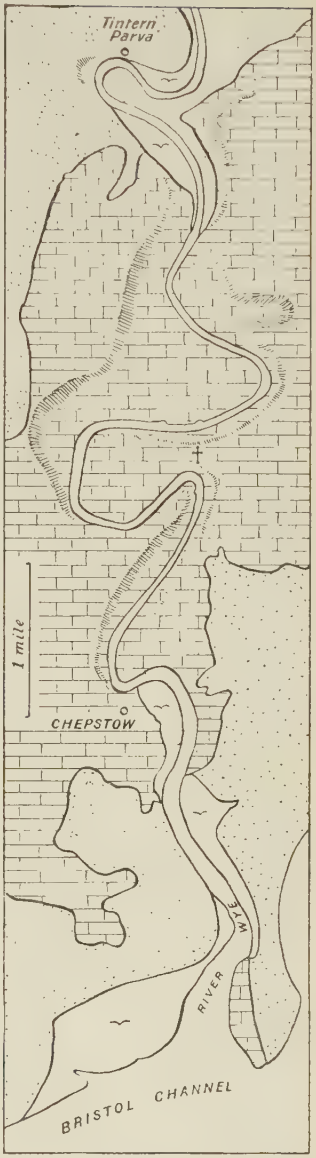

FIG. 103.—INCISED MEANDERS OF THE WYE.
The shaded cliffs show the limits of the old flood-plain from which the alluvium has now been removed. Close stipple, Old Red Sandstone; brick shading, Carboniferous Limestone; open stipple, New Red. † Marks the site from which the view (Fig. 104) is taken.

sediment, some of which it drops in its own bed, building it up until it stands above the general level of the plain. By lateral movement and by floods it builds the flood-plain higher and higher, and at the same time it may push it forward as a delta-plain into the sea. The farther the delta is advanced, the less the slope of the flood-plain becomes, and the more easily is it formed.

Rejuvenescence.—Rivers thus pass from youth to maturity, from maturity to old age, when they carry along only the finer washings of the now gentle slopes and wander lazily to the sea. This state is rarely

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Fig. 104.—Curve of the Wye near Chepstow: an Incised Meander.

reached, however, for the land may be raised above sea-level and the rivers given a new life; they become rejuvenated, and begin to corrade vigorously downwards, sinking their meanders deep into the flood-plains and cutting serpentine valleys or gorges in the floor beneath, in which irregularities (rapids, etc.) are again developed. Amongst English rivers possessing these 'incised meanders,' the Wye near Chepstow, the Wear at Durham, and the Tamar in Devon, are good examples.

When the river has cut down to near its new base-level, it will once more begin to corrade sideways and form a new flood-plain within the old one, but at a lower level. Thus patches of the old flood-plain will be left here and there on either side of the new valley as flat **terraces.**

If there is another uplift the deposits of the second flood-plain will form terraces above the third and latest.

Tributary streams behave like the trunk streams. Some have well-developed flood-plains at a low grade, which often merge insensibly with that of the larger stream. In other cases the gradient is steeper and more rock waste is brought down than can conveniently be carried away, so that it gives rise to a sheet of débris in the form of a fan spreading out from the side valley on to the plain below. Such 'alluvial fans' are gently inclined, and consist of fine detritus, if the side valley has a gentle grade and enters the main valley nearly on a level; but if the tributary is a torrent the detritus will be coarse and the angle of slope of the fan high. When swollen with heavy rain, the tributary frequently alters its position on the fan (with disastrous results if cultivated and inhabited) and runs between new banks of waste. The fan of a large tributary may force the main river across its valley into the opposite bank, or obstruct its course entirely and form a lake.

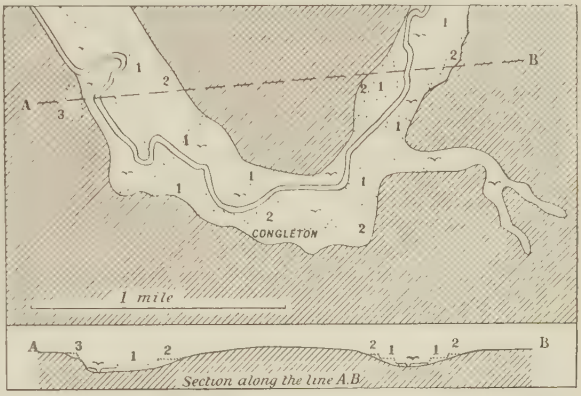


FIG. 105.—TERRACES OF THE RIVER DANE, CONGLETON, CHESHIRE.

The alluvium is not shaded.

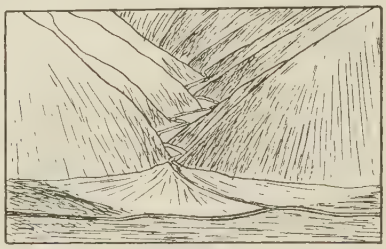


FIG. 106.—DIAGRAM OF AN ALLUVIAL CONE.

Effect of Rocks on River Development.—Suppose a river is running down a slope consisting of a planed surface of rocks of different degrees of hardness and tilted at an angle.

The hard beds resist the corrasion of the stream more than the soft, so that the latter will be hollowed out at *f* (Fig. 107), and water will fall over the hard beds, cutting them back, partly by undermining and

partly by loosening the jointed blocks at the edges of the falls. The fall will give increased corrasive power to the stream at that point, but below it the gradient will be less than the average, and the river, finding a temporary base-level on the soft rock, will form a flood-plain, which is widened as the fall retreats slowly up-stream. The river meanders freely on the soft beds, but is restricted to a gorge through the hard rocks where it is vigorously corrading downwards to base-level. It may meander in the gorge after base-level is reached.

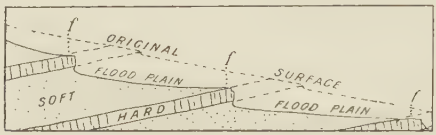


FIG. 107.—EFFECT OF HARD AND SOFT ROCKS ON RIVER DEVELOPMENT.

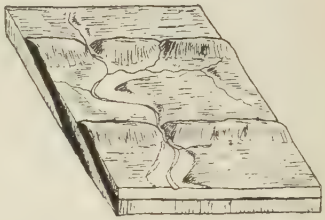


FIG. 108.—DIAGRAM SHOWING DEVELOPMENT OF ESCARPMENTS FROM HARD ROCKS (black) AND EASY REMOVAL OF THE SOFT ROCKS BETWEEN THEM.

While the gorge is being cut, tributary streams are formed along the strike (p. 42) of the soft rocks on either side of the low flood-plain. The original river is called a 'consequent' stream—*i.e.*, one consequent upon uplift—and is a 'dip' stream if it runs in the direction of the dip. The tributaries are 'subsequent' streams, or 'strike' streams, formed subsequently to the consequent; they develop valleys between the outcrops of the hard rocks, which are caused to stand out in relief as long hills called 'escarpments'* (p. 107). The bevelled edge of the bed is the 'escarpment,' or 'scarp,' the gently inclined surface is the 'dip-slope.'

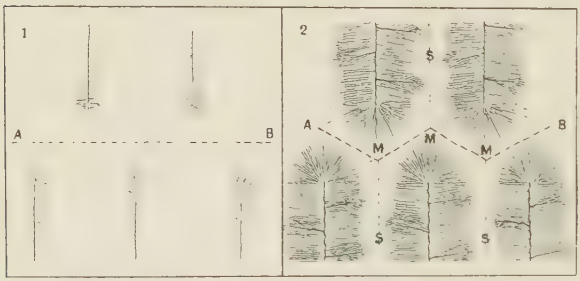


FIG. 109.—DIAGRAM OF AN IDEAL DRAINAGE SYSTEM.

1, the first stage; 2, a later stage, showing zigzag watershed and secondary divides; A, B, watershed; S, secondary divides; M, M, mountain peaks.

An ideal drainage system would be formed on an ideal uplift consisting of a single kind of rock. Suppose we have a simple anticlinal arch, with

* Escarpments may also be produced by ordinary weathering, apart from the action of rivers.

rainfall spread evenly over it. The summit ridge above the axis of the fold forms the divide or watershed.* The water in this ideal system bursts out as springs at regular intervals on each side of the watershed, each spring draining an equal area and giving rise to consequent streams. The coombes at the heads of the valleys encroach upon the divide and cause it to become zigzag. The same process is then repeated upon the secondary divides and so on, until a regular drainage system is established (Fig. 109). Ideal drainage, however, occurs very rarely in Nature.

River Capture.—Let the consequent streams flow from the watershed AB across rocks of different degrees of hardness (H and S, Fig. 110), one stream, A, being more powerful than the other, B, A therefore lowers its valley more quickly than B, its tributaries develop speedily in the softer rocks, and rapidly cut back into the secondary divide between the two rivers. In course of time the tributary C may tap the tributary D, belonging to B, and switch off its waters into its own channel, for C's valley is lower than that of D. Further cutting back on the part of C may rob B of all its upper waters, and an empty gap (wind-gap) will be left at E, with a shrunken, diminished stream below. This in a case of 'river capture' or 'piracy.' C has beheaded B, and seized its head waters, thus becoming quite an important river. If other consequents lie beyond B, C might pass from conquest to conquest, working along the soft rocks and capturing the head waters of several streams. In this manner the Yorkshire Ouse, a subsequent stream tributary to the Humber, captured the head waters of streams now called the Swale, Ure, Nidd,

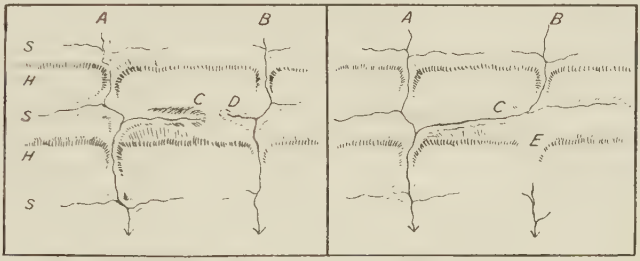


FIG. 110.—DIAGRAM ILLUSTRATING RIVER CAPTURE.
AB, watershed.

* A watershed or divide is, strictly speaking, a line separating one stream or system of streams from another, or the crest line between the slopes leading to different streams or rivers. A river-basin—the land from which a river gathers its waters—is cut off from the neighbouring river-basins by an outer divide, and is intersected by divides of smaller extent, separating the tributaries from one another. A well-marked watershed like that of the Pennines, which separates waters flowing into two seas, is sometimes called a water-parting.

Wharfe, Aire, Calder, and Don, which once ran direct to the North Sea, as the Tyne, Tees, and Wear yet continue to do.

Patterns of River Systems.—If the rocks at the surface are of the same texture and solubility, the streams find no belts especially adapted to the development of valleys, neither are there any harder layers competent to form escarpments ; hence the tributaries are due to minor accidents of the surface, and usually result in forming a system whose branches are like those of an elm-tree. Such a system is said to be ' self-grown.'

In cases like that described above, where the tributaries have worked their valleys along the softer rocks and captured the head waters of other streams, the river with its branches resembles the stems of a vine on a trellis. Such a drainage system is said to be a ' trellised ' drainage ; it has become ' adjusted ' to the structure of the rocks over which it flows.

In the Weald the rivers have become adjusted, but in the Cleveland Hills, although the rocks are competent to form ridges, the subsequents have not yet had time to develop in the same way. In Central England most of the rivers show adjustment of drainage. From the Cotswold Hills a series of rivers once ran eastwards as consequent dip streams, but their head waters have been gathered up by subsequents, such as the Great Ouse, working along the soft rocks.

In Munster the eastward streams follow synclines, and the southward streams cross the intervening anticlines in gorges. The whole district was once covered with sediment, uplifted and tilted to the south, when the southerly flowing consequents were superimposed (p. 92) upon the folded rocks below. Subsequently the east and west tributaries were developed, and capture after capture has taken place, until the present right-angled arrangement has been established.

Diversion of Drainage by Ponding.—If a river finds itself unable to cut its way through a dam, which has somehow arisen across its course (see p. 136), the waters will accumulate as a lake, and finally flow over the barrier as a waterfall. Should the barrier, however, be higher than some low part of the divide between this valley and the next, the water will flow over this ' col ' and become part of another river system. The silting up of the lake or its drainage by lowering of the col is then merely a question of time. The stream occupying the Windermere Valley before the Ice Age flowed down a valley now filled with the boulder clay which forms the dam holding up the water. The issuing stream flows over a low col into a neighbouring valley.

Consequent Drainage.—When land is uplifted, the first drainage takes the shortest course to the sea, whether it runs directly from an

uplifted ridge or whether it follows synclinal valleys lying between anticlinal folds.

A good example of consequent drainage is furnished by the Weald of Kent, which was once a low dome of chalk resting upon and covered by sands and clays. The longer axis of the dome extended into the North of France. Rivers flowed

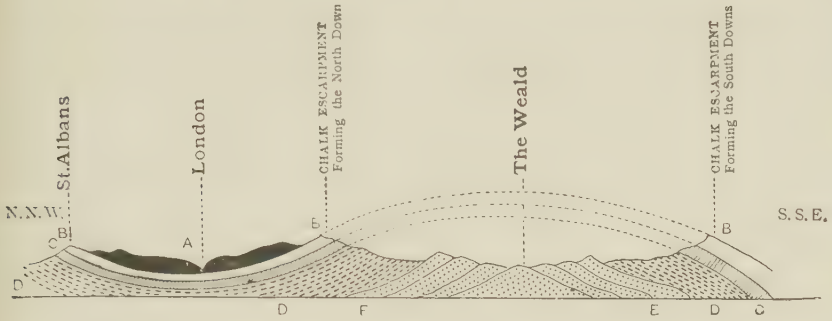


FIG. 111.—THE LONDON BASIN AND THE WEALDEN DOME.

A, London clay ; B, B, chalk ; C, C, lower greensand and gault ; D, D, Weald clay (mainly) ; E, E, Hastings sand.

regularly in all directions from its surface, and cut deeply into the rocks, until the softer beds below the chalk were reached. Whilst the chalk was being removed from the centre of the dome, the rivers sank their gorges through the ring of chalk hills that now remain with scarped edges facing inwards. Thus, the Wealden rivers

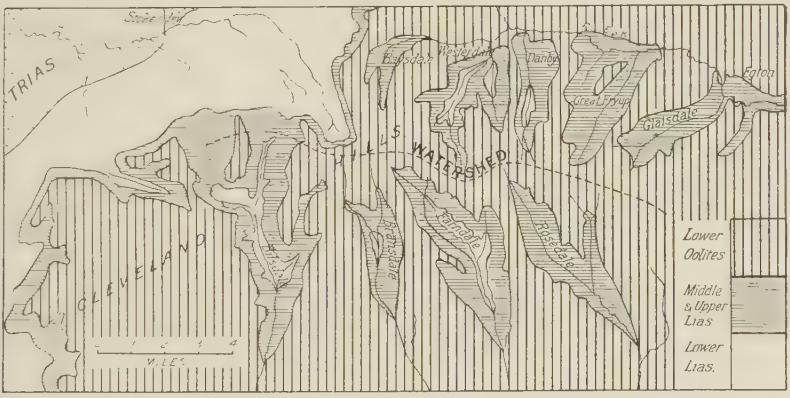


FIG. 112.—THE CLEVELAND HILLS, SHOWING CONSEQUENT DRAINAGE SYSTEM.

rise on the low central plain, and plunge through gorges in the escarpments of the North and South Downs.

The drainage system of the North-West Cleveland Hills is another case in point, but the process has not gone so far ; the higher inner parts of the uplift have not been entirely removed. An east and west anticlinal uplift, with beds dipping to north and south, gave the initial direction to the streams.

Inconsequent Drainage.—Occasionally the drainage system bears no relation whatever to the rocks upon which it flows. In the English Lake District the strike of the rocks is east and west, but the drainage radiates, like the spokes from the hub of a wheel, from a point near the mountain group of Scafell.

Round the older rocks of the Lakes there is a ring of younger rocks (Mountain Limestone, etc.) inclined in such a manner that if their slopes were continued inwards they would meet over Scafell. Hence it is assumed that the Mountain Limestone once covered the old rocks as a flat sheet ; that the rocks were then domed up, and a consequent radial drainage instituted on the limestone, and transferred to, or ' superimposed ' upon, the old rocks when the former was denuded.

Floods.—The amount of work accomplished by the ordinary rivers of Great Britain and Ireland is apt to be underestimated, because at most seasons the flow seems to be gentle and there are no very great changes in the river banks. The power of a river, however, should be gauged when it is in flood, and the volume and transporting power of the water are at a maximum. Large boulders, which at other times lie undisturbed, are shifted easily, stones are whirled along, the river banks are undermined, especially at the bends, and trees growing on the bank are swept away by the irresistible rush of the water. Sediment is deposited far and wide over the flood-plain where the pace of the flow is checked in the shallows. When the waters subside, the banks are often found to be much altered, the river may even have changed its course, and the lately submerged fields are covered with a layer of silt and mud.

The floods invade the low quarters of towns or swamp the basements of houses by rising through the alluvial deposits, and may demolish bridges, weirs, and buildings. Villages situated on ridges rising from the plain may be so completely isolated that provisions have to be brought in boats. Animals are frequently swept away, and such damage done to springing crops that the grain must be sown again. The forests, which used to hold up the water and part with it gradually, have been removed by man ; the fields are well drained, so that the run off is accelerated and the river channel too quickly filled.

Great floods occurred in Moray in 1829, when $3\frac{3}{4}$ inches of rain fell in twenty-four hours, and some of the streams rose 50 feet above their normal level. In 1795 a tremendous flood caused the Trent to burst its banks and cover 20,000 acres between the river and Lincoln City. Again, in 1875, thousands of acres of land were submerged, and the traffic

of the district brought to a standstill. At Paris the Seine recently rose 27 feet 10½ inches above its bed—instead of the normal 8 or 9 feet—and gave rise to extraordinary scenes in the streets of the capital.

Upon low-lying flood-plains and deltas the rivers have often been used as a weapon of offence; by breaking down the banks thousands of lives have been destroyed. Floods, however, may serve more useful purposes. Late spring floods leave deposits of rich loam on the meadows, and so thoroughly soak the subsoil that fine hay-crops are insured. The agricul-

From Geological Survey Memoir.

Fig. 113.—The Trent in Flood, Nottingham, 1875.

tural population of the Nile Valley is dependent upon the floods for prosperity. Without the water to be stored for irrigation and the thick deposits of rich fertile mud life would be impossible. In such desert districts every resource of the engineers is brought to bear upon the problem of storing water and extending the annual floods of the rainy season by means of dams, and then conveying it to distant spots in artificial channels. Even now schemes are on foot to bring wealth once more to the Tigris and Euphrates Valleys by extensive irrigation works.

CHAPTER X.

Valleys and Mountains.

Slopes are common to both mountains and valleys, so that when we descend a mountain or hill-side, it is often difficult to say when the mountain-slope ends and the valley-slope commences. Again, mountains and valleys have frequently a common origin, the forces or agents which have given rise to the one often give rise to the other; hence it is convenient to consider the two as closely together as possible.

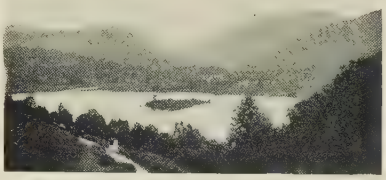
In temperate regions the slopes are determined in the first place by the action of running water. Just as the ideal profile of a river's course (base-line of erosion) is a curve descending sharply near the source, and becoming flatter near the mouth, so the ideal cross-section of the side of a valley is a similar curve. But if a valley is cut into a series of alternating beds of hard and soft rock, the former, being more resistant, will form ledges with steep faces, whilst the softer rocks between the hard beds will be weathered away to a gentler inclination. Thus the profile is made up of steep scarps and sloping ledges, constituting an irregular curve, which, when viewed from a distance, resembles the curve of water-erosion. Many mountains at a distance of several miles seem to possess slopes corresponding with the curve of water-erosion, but at close quarters are found to be broken up by frowning precipices alternating with gentle inclines. At the foot of each scarp a talus accumulates at the angle of rest, and sweeps out over the softer rocks towards the next ledge (Fig. 114).

A. W. Andrews.

Fig. 114.—Irregular Mountain Slope made up of Alternating Scarp and Talus: the Dolomites.

Valleys are generally wider at the top than at the bottom, because during the whole time that they are being deepened the slopes are attacked

by the atmospheric agents, and therefore a sharp angular top to the side of a valley or crest of a hill is rare. At the summit of a slope a clothing of vegetation tends to hold the water, charged with vegetable acids, against the rock, and prevents the formation of many runnels, hence the concave curve of water-erosion is replaced by a convex curve similar to that produced upon the granite of Dartmoor by the chemical rather than the mechanical action of water (p. 59). The Chalk Downs, attacked mainly by rain and weather (surface drainage being absent), have the characteristic rounded outline well shown by most vegetation-clad escarpments. In Wales such hills are called 'moels.'* Sometimes vegetation will grow only upon one side of a mountain; thus, in the English Lake District the western slopes, which receive most of the sun and rain, are often moel-shaped (Fig. 115), but the eastern have the stream curve. On such a hill the divide will shift from east to west as the streams cut back. *In wet tropical regions*, where vegetation is dense, the moel-shaped hill is seen on all sides.



B. Smith.

FIG. 115.—MOEL-SHAPED HILLS, GRASMERE, WESTMORELAND.

In arid regions (*e.g.*, polar and sub-tropical) the water-erosion curve is absent, the profiles of the slopes being determined chiefly by structural planes in the rocks. Weathering is mainly mechanical, and since the valley walls are not rapidly weathered, precipitous slopes are common. In the absence of vegetation the wind removes from exposed positions the scree material, which softens the outlines in temperate regions. In dry regions we should therefore expect horizontally bedded rocks to form vertical cliffs. If the rocks are inclined, the major joint planes are inclined, and the resulting slopes resemble those of the top of a rectangular block held with one corner higher than the others, the joints being supposed parallel to the sides. This is the so-called 'house-roof structure' which is common to desert mountains and the summits which rise anywhere above the snow-line. The essential factors are (1) the absence of running water, (2) the active operation of frost or temperature extremes. The Matterhorn (Fig. 149) owes its peculiar shape mainly to these factors operating upon rock with inclined structural

* Dr. Marr suggests that all hills with this shape should be called 'moels.'

planes, the waste being removed by snow and wind,* aided by gravity. In the Antarctic (South Victoria Land) many of the mountains exhibit perfectly the house-roof structure.

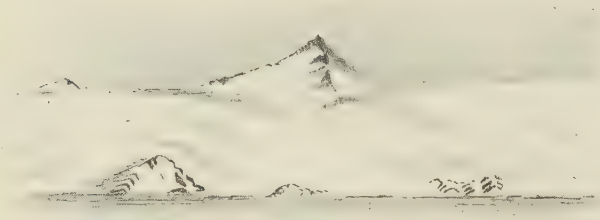


Fig. 116.—Christmas Mountain (with house-roof structure), S. Victoria Land. (After E. A. Wilson.)

Valleys. — Most valleys, like rivers, pass through various stages of development—from youth to maturity, from maturity to old age. *Young valleys* have steeply sloping sides, and the valley bottom is little or no wider than the river, which is cutting downwards. If the rocks are resistant to weathering, the walls will be precipitous, and the valley becomes a ravine, gorge, or cañon. When the rocks are less resistant, the top is wider than the bottom, and the slopes are determined by the curve of water-erosion. Such a valley is said to be **V**-shaped.

E. L. Guilford.

Fig. 117.—Head of a Young Valley, Whitbeck, Cumberland.

As we ascend a young valley, one of the most striking features is the way in which the hill-spurs, due to the winding course of the stream, project in turn from the opposite sides, and appear to overlap (Fig. 100). Another characteristic is the general absence of a flood-plain, instead of which there are sometimes small lakes or patches of alluvium, each followed by a waterfall. The base-level of erosion is far from being reached.

* Mr. Whymper tells us that once, when on the Matterhorn, 'we clutched our hardest when we saw stones as big as a man's fist blown away horizontally into space.'

When the stream begins to meander, it widens the valley bottom by undercutting the walls, whilst the top is opened out by atmospheric denudation, which develops scarp-ledges if the rocks admit of it. A gorge becomes broader below and wider at the top. In less resistant rocks the profile is like that of a shallow basin; overlapping spurs are consumed; the valley walls straighten in places, and are sloped back at a wide angle except where the stream is actually undermining them. *The valley is now mature.* Its almost continuous alluvial flat may be interrupted here and there by partially silted-up lakes, followed by rapids and narrows representing the old waterfalls and gorges.

Old valleys are widely open, the walls are smoothed and sloped back as far as possible, and enclose a broad flood-plain; waterfalls and lakes are obliterated, because the running water has reduced everything almost to base-level. The old-age stage of development in all rivers commences near the sea where the slope is low, and if uninterrupted creeps slowly upstream. When the headwaters attain old age, the whole country is near base-level.

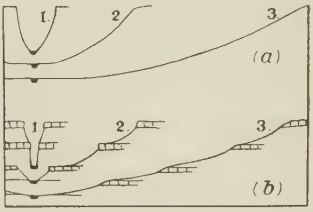


FIG. 118.—VALLEY PROFILES, FROM YOUTH TO MATURITY.

(*a*), in soft rocks; (*b*), in alternating hard and soft rocks.

Valleys are of two kinds:

1. Valleys arising from earth movements.
2. Erosion valleys.

One type grades insensibly into the other because, in the first case, the valleys must be modified by erosion, and in the second case the rocks must have been raised above sea-level.

1. *Valleys due to Rock Folds.*—A river may find a broad synclinal trough a convenient path to flow along, but will modify it to some extent by erosion. Streams flowing in such valleys are necessarily consequent upon uplift. The valley of the lower course of the Thames in the London basin is a good example.

Valleys due to Faulting.—Sunken tracts of land between two nearly parallel faults, although often of enormous size, are comparatively rare. The best example is the great Rift Valley of East Africa, which extends from Lake Tanganyika to Albert Nyanza, and thence to Lake Rudolph, where a second branch from near Kilimanjaro unites with it, and then, leaving Abyssinia on the west, reaches the Red Sea. The Jordan and

the Dead Sea lie in a similar rift. The floors of some of these sunken tracts are broken by cross faults, which leave one portion higher than another. In the deepest hollows are the lakes. Parts of the Rhine Valley also lie in a rift between two or more faults.

In the Lowland Plain of Scotland young rocks are let down between older ones to form a true rift valley. The Vale of Eden in Cumberland lies above a sunken tract, but only the eastern side is faulted down (Fig. 218), the Mountain Limestone of the Pennines being upthrown to form a tilted block — a type of structure common in some parts of America.

Fig. 119.—Lowland Plain of Scotland.

Carboniferous rocks (black), on Old Red Sandstone (stippled) in rift between two faults.

Valleys due to Faulting and Erosion combined.—A spring may give rise to a small stream which works back quickly in the shattered fault-rock. Again, a river, running diagonally across a fault, or shattered belt, will become 'adjusted' to these lines of little resistance, and form a straight valley. Dr. Marr has shown that east of Windermere the valleys of Troutbeck, Kentmere, and Long Sleddale are straight, and determined by streams working along belts of faults.

2. The formation of erosion valleys has already been fully discussed (pp. 82-86, 96-97); they usually run along the strike of the softer or more easily eroded rocks, but cross the strike of the more resistant rocks. Again, valleys in soft rocks generally have a softer and more gentle profile than those cut in hard rocks. In young valleys want of symmetry is due to structure and rock texture (Fig. 120).

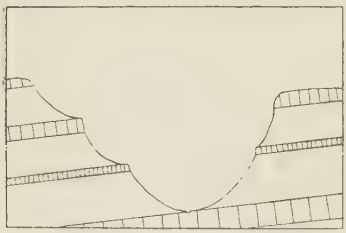


Fig. 120.—Want of Symmetry in a Young Valley, due to Rock Structure.

The methods of formation given above account for most normal river valleys; there are certain abnormal forms which we must briefly consider.

Hanging Valleys. It has been noted above (p. 81) that in a mature valley system the laterals join the main valley at accordant grade: there is no sudden drop from the mouth of the side valley to the

main valley. In many cases, however, side valleys enter the main valley at a high level, and their streams tumble in cascades down its sides; in other words, the grade of the later valley is discordant with that of the main valley. Such valleys are said to be 'hanging,' and are caused by the overdeepening of the main valley by (*a*) water, (*b*) ice.*

(*a*) If the erosive power of a stream is increased and rejuvenated by uplift at its head, or by increase in volume due to diversion of drainage into its channel, it will rapidly cut downwards, and leave its tributaries (which have been less affected) in their old positions, so that they now mouth above the main stream. But the lowering of the main valley will rejuvenate the tributaries by increasing their fall, hence they will rapidly lower their beds, and establish an accordant junction with the main stream before the latter has been able to convert its new **V**-shaped valley into a broad valley with a flood-plain. Many young hanging valleys near the west coast of Scotland have been formed in this manner.

(*b*) In glaciated regions hanging valleys open upon the flanks of wide valleys with flat floors. Their method of formation by the destructive or protective action of ice is discussed in Chapter XII. and Appendix A.

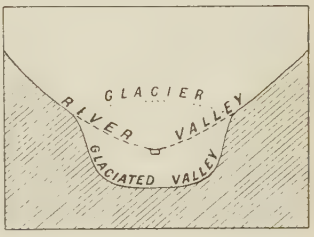


FIG. 121.—A V-SHAPED CONVERTED INTO A U-SHAPED VALLEY.

Glaciated Valleys.—The lower part of a valley occupied by a glacier assumes a smooth, trough-like or **U**-shape (p. 129), whilst the higher parts—above the ice-limit—exhibit the gentler slopes of atmospheric weathering, diversified by frost-riven crags and pinnacles; hence the profile is somewhat like that in Fig. 121, which shows a typical **V**-shaped valley converted into a **U**-shaped glaciated trough. Looking up such a valley the absence of the overlapping spurs common to immature river valleys is noticeable—the ice-stream has ground them almost entirely away (Fig. 155).

Buried Valleys.—Many valleys have been filled to the brim, and hidden so completely from sight that their existence would have been unsuspected had not borings or diggings proved the old valley floor. The streams, which formerly occupied them, now follow other courses. In their march across country the glaciers of the Ice Age frequently filled up river-courses with débris, so that the rivers were diverted into

* Or possibly (*c*) by water and ice. (See Appendix A.)

new channels. These buried valleys are common in all glaciated countries, and ours is no exception. Quite recently a deep channel has been discovered by borings near Hitchin, reaching such a depth that, if the boulder clay (p. 133) filling it were to be removed, the sea might enter and come far inland.

Valleys may also be buried by great outpourings of lava, as in Iceland, whilst in deserts the wadies are sometimes obliterated by being filled with rock waste or blown sand.

Drowned Valleys.—Should the land be depressed slightly, the sea would enter the valleys and drown them. This, in fact, is what has happened to many of the valleys of the British Isles whose mouths open on the sea as estuaries, lochs, loughs, or fjords (p. 165). In some cases their continuations may be traced for miles beneath the sea waters. Cork Harbour is a splendid example of the submergence of a system of transverse and longitudinal valleys.

It frequently happens that a river—*e.g.*, the Tamar, Devonshire—with incised meanders ends in an estuary. In such cases the elevation causing rejuvenescence has been followed by slight submergence. The islands and narrow parts of drowned valleys were the ridges and gorges in the old river system.

Consider a small area in the East of England. If there was a depression of but 80 feet, the sea, entering the Humber and the Witham Gap through the Lincoln Heights, would mingle with the Trent near Nottingham, whilst many miles of intervening low ground would be inundated, to form an inland sea stretching from Newark to York, dotted with islands and fed by long tributary estuaries from the west. At the same time the whole of the Fenland and river valleys opening upon it would be deeply submerged.

Dry Valleys.—Since most valleys are the result of stream erosion, those which do not contain streams seem to require explanation. They must be distinguished from the valleys in arid or semi-arid districts, which are swept at intervals by torrential floods, but are dry for the rest of the year. In many districts permanently dry valleys in rocks of a pervious nature, such as chalk, limestone, or sandstone, have all the attributes of ordinary river valleys, with the exception of the river and its alluvial flat. The dry valleys of the limestone districts of Yorkshire, Derbyshire, and Somerset, are explained by the numerous swallow-holes of those regions; the rivers have been engulfed and now pursue their courses underground (p. 76). The dry valleys of the Chalk Downs are probably due to rain falling on the frozen (and therefore impervious)

chalk at the close of the Ice Age. In sandstone districts dry valleys may be caused by lowering of the water table which fed the streams, either through decrease in the rainfall or by the pumping operations of water companies.

Other dry valleys are the result of diversion of drainage by river capture, or interference by ice, which turned rivers out of their courses and held up the drainage (p. 135), so that the escaping waters cut deep and narrow valleys which are now left high and dry.

Destroyed Valleys.—Gravels are frequently found at high levels in such positions that they could not possibly have been deposited by rivers if the land had its present surface relief. These gravels owe their preservation to their greater resistance to erosion than the walls of the old valleys in which they were laid down. The sides of the valleys have melted away, so that the gravels upon their floors are now frequently the summits of hills. Long gravel-capped ridges extend from near Bolsham, through Wilbraham, Cambridge, Oakington, and Long Stanton, to Willingham, and were probably continuous with the estuarine gravels of Chatteris, Doddington, and March. They have no connection with the Cam Valley, but were formed in a valley now destroyed.

Waterfalls.—Waterfalls, found only in young and semi-mature valleys, in which there are inequalities still to be removed, are formed by water falling over either vertical or steeply inclined rock faces; *cascades* fall in steps, whilst *rapids* are caused by rocky declivities in the channel, or a series of small rock ledges. Above each rocky barrier across a river's course there is, on the softer rocks, a wide flood-plain, forming a local and temporary base-level established whilst the river is slowly sawing its way through the harder belts.

The commonest type of fall is due to a hard sheet of rock lying between softer beds. If the rocks are horizontal or dip upstream, the swirling water below the fall will undermine the harder rock and bring it down; thus a gorge will be formed by the waterfall slowly retreating upstream. The pool below the fall is deeper than other parts of the stream channel, because the stones and rocks are swept round and round, and then deposited farther downstream. In the above case rapids may be encountered before the actual edge of the fall is reached; but if the beds are dipping downstream, rapids are more common than waterfalls, because the water attempts to burrow beneath the rising rock ledges, boils over them, and then runs down their dip slopes. Waterfalls,

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FIG. 122.—HIGH FORCE, TEESDALE.

A waterfall due to the nearly horizontal Whin Sill, intrusive in soft Carboniferous rocks. (See Fig. 130.)

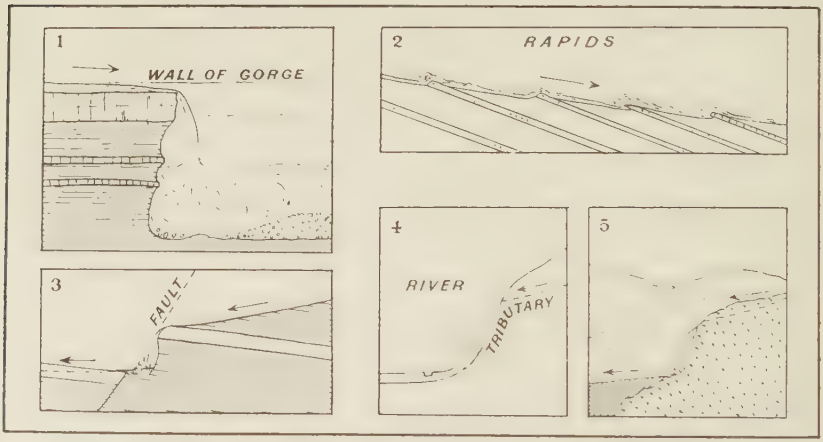

FIG. 123.—WATERFALLS.

1. Hard rocks being undermined: fall retreating upstream. 2. Rapids. 3. Fall formed at fault scarp. 4. Waterfall from mouth of a hanging valley. 5. Fall at junction of igneous and sedimentary rock.

however, will occur if the fall of the stream is much greater than the dip of the beds downstream. Other methods of formation of waterfalls are shown in Fig. 123.

Mountains and Hills, like valleys, may be considered under two main heads :

(1) Those due to earth movements.
(2) Those due to erosion.

It must be clearly understood that the one type may shade insensibly into the other. There are also (3) mountains or hills of accumulation, such as volcanoes and sand dunes, but these are dealt with in other chapters.

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FIG. 124.—THE GREY MARE'S TAIL, MOFFAT.

A waterfall from a hanging valley.

(1) *Symmetrical Rock Folds.*—This type of structure is typically developed in the Juras and the Appalachians, where the mountains lie fold behind fold—a series of earth waves—the anticlinal mountains being accompanied by synclinal valleys, the whole modified more or less by erosion (Fig. 125).

Unsymmetrical Folds.—The Mendip Hills furnish a good example of mountains formed of unsymmetrical anticlines, the rocks being sometimes even overfolded (p. 176). Monoclinal structures, called 'hog backs,' in the western territories of North America are often found in plateau regions; the nearest approach to this structure in England is afforded by the Isle of Wight, the central rib of high land running east and west being the denuded middle-limb of the fold. Dome-shaped uplifts, due to intrusive masses of igneous rocks which arch up the overlying sediments, are extremely common in the Henry Mountains, U.S.A.

The Alpine structure is a compound type, and consists of a series of folds resulting in the so-called 'fan structure' (Fig. 125). The outer folds are minor symmetrical ridges parallel with the axis of the main

chain; the inner folds, owing to increased pressure, become inverted, and their axes dip inwards; thus, younger rocks may be tucked away in the hearts of such mountains with older rocks apparently overlying them. Fan structure is developed in the Lead Hills and other hills in the Southern Uplands of Scotland.

Every type of fold has its accompanying fault (Fig. 48); thus, mountain structures due to folding have their counterparts in mountains due to faulting.

On the great plateau traversed by the Colorado Cañon there are many bold mountain scarps produced by faulting and tilting of different blocks of the plateau. In England weathering tends to destroy fault scarps, but the great Pennine fault throws down the Mountain Limestone of Cross Fell to a position beneath the floor of the Eden Valley. Again, the huge escarpment of the same limestone near Giggleswick and Settle, Yorkshire, is directly due to a fault, and has probably persisted as a scarp since the time of its formation. The Black Mountains of Oregon are the inverse of the rift valleys of East Africa; and the Alpine structure is repeated in mountains in which the reversed folds are replaced by reversed faults or thrust-planes.

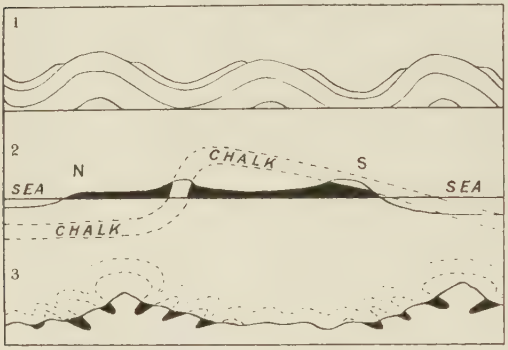


Fig. 125.—Mountain Structures.

1. Symmetrical rock folds of the Juras. 2. Monoclinal structure of the Isle of Wight. 3. Fan-structure. (Younger rocks black.)

(2) Many mountains are the result of the sculpturing of masses of rock by atmospheric agents; they are frequently called *mountains of circumdenudation.*

If we turn for a moment to the ideal drainage system (p. 88), we note that the head of each valley is overshadowed by a mountain, which is the butt end of a secondary watershed upon the other side of the water-parting. In a similar manner, but under less ideal conditions, mountains may be carved from any uplifted mass of land, but the final results will be largely influenced by the geological structure of the rocks operated upon. Consider an elevated tract of nearly horizontal, stratified rocks, such as the high plateau of West Yorkshire, near Settle and Ribblesdale, where the Mountain Limestone is overlain by shales,

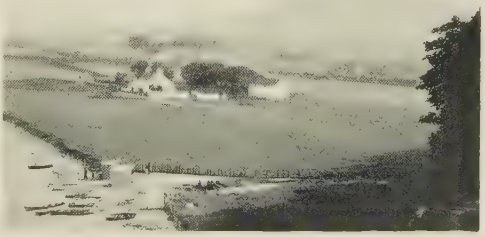
limestones, and grits, the hard and soft beds alternating. This plateau has been so deeply trenched by erosive agents that flat-topped hills

A. W. Rogers.

FIG. 126.—A MOUNTAIN OF CIRCUMDENUDATION, CAPE COLONY.
The hard bed capping the mountain is of Table Mountain Sandstone.

(*mesas*), each capped by a hard bed of grit or limestone, are left standing in solitary isolation upon the Mountain Limestone.

Ingleborough, Whernside, and Pennyghent are good examples of such mountains of circumdenudation. The Peak of Derbyshire also is a flattened basin of grit, forming a small tableland at a height of about 2,000 feet above sea-level. Its edges form wild craggy cliffs, with deep river gorges winding far back into the heart of the plateau. Remnants of the basaltic lava-flows of Antrim and the Isles of Scotland form similar flat-topped mountains (Fig. 127). Within the outer walls of the Colorado Cañon there are many isolated mountains of circumdenudation, called *buttes*, which are carved out of the plateau, and therefore never project above its level, yet are quite a considerable size, since the cañon is sometimes 6,000 feet deep.

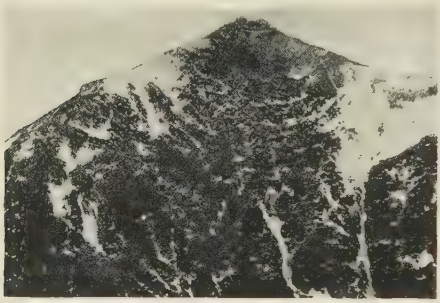


A. T. Metcalfe.

FIG. 127.—LURIGETHAN FROM THE STRAND, CUSHENDALL, ANTRIM.
A mountain of circumdenudation consisting of Triassic and Cretaceous rocks, capped by Tertiary basalt.

Such hills are as truly table mountains as the hills capped by the Table Mountain Sandstone in Cape Colony (Fig. 126). As denudation progresses, the flat tops will become smaller and smaller, until finally the mountain loses its protective capping, when the soft beds beneath are rapidly denuded until a second hard bed arrests the process for a while.

Mountains of circumdenudation are more complex when the rock structures are complex. Those of the Central Highlands, for example, composed of intensely old, altered, and hardened rocks, form, perhaps for this very reason, some of the highest mountains in the British Isles. They are carved from an old worn-down mountain region, now uplifted to form a tableland, dissected by glens 2,000 to 3,000 feet deep—a fact best appreciated by viewing them from a distance, when summit after summit will be seen to rise to the same height (Fig. 138).



G. P. Abraham.

FIG. 128.—SNOWDON PEAK FROM EASTERN RIDGE.

Synclinal arrangement of strata shown by snow resting on ledges.

The mountain groups of North Wales and the English Lakes have been similarly sculptured from rocks with varying structures. Their highest summits, Snowdon and Scafell, are composed of volcanic rocks, dipping into the mountain in each case in the form of a syncline (Fig. 128), a structure which offers very great resistance to denudation. 'The great height is not due to the intrusion or piling up of igneous masses. They were, indeed, after the volcanoes became extinct, covered by several thousands of feet of newer strata, and at length all disturbed together, thrown into great rolling curves, and then denuded, the present mountains being, so to say, carved out and left at a greater elevation, because the hard felspathic igneous rocks of which they consist were better able to withstand degradation than some of the softer slaty rocks with which they are associated.'*

Mountains formed of intrusive masses of plutonic rock consolidated beneath the surface are, by their very origin, mountains of circumdenudation. In this class we may therefore include the Mourne Mountains, Ireland (granite); the mountains of Arran (granite) (Fig. 131), of Skye (granite and gabbro) (Fig. 170), of Cairngorm (granite), in Scotland; and Shap Fells, the Cheviots, and Dartmoor (granites) in England.

* Lord Avebury, 'The Scenery of England,' p. 257.

Escarpments frequently assume the majesty of mountains, especially if formed by sheets of intrusive or volcanic rock. The Pentland Hills, for

H.M. Geological Survey.

Fig. 129.—The Escarpment of the Middle Lias, Vale of Belvoir, Leicestershire. (See Fig. 316.)

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Fig. 130.—The Escarpment of the Whin Sill (intrusive in Carboniferous rocks), Northumberland.

Hadrian's Wall (A.D. 124) is carried along the edge of the escarpment at this point.

example, consist of a series of escarpments made up of lava flows interbedded with Old Red Sandstone. Cader Idris and Arenig Mountains,

North Wales, also owe their elevation to the resistant nature of the inclined sheets of igneous rock. The Whin Sill, intrusive in the Carboniferous rocks of Northumberland, forms a scarp running for miles.

We may also mention the Quantock Hills (1,262 feet), composed of sandstones and slates of Devonian age, with a westward facing escarpment; Brecknock Beacon (2,910 feet), carved entirely by atmospheric action from nearly horizontal beds of Old Red Sandstone; the escarpment of Cleve Cloud (1,093 feet), consisting of oolitic limestones, and that of Wenlock Edge, formed of limestone on shale, one of the longest, sharpest, and straightest escarpments in Great Britain.

Influence of Rock Structure.—The rocks composing a hill or mountain will have a great influence upon its appearance, whether it

A. T. Metcalfe.

FIG. 131.—MOUNTAINS FORMED OF GRANITE, ARRAN.
In middle distance, sedimentary rocks; in foreground, the same glaciated.

be situated in an arid or a rainy district. Horizontally bedded rocks will always assume terraced forms, the hard ridges forming scarps, and the softer beds gentle slopes. Mountains formed of slates, like Moel Wyn (North Wales) or Skiddaw, have a soft, smoothly sloping appearance, broken here and there by steep, often knife-like, ridges, due to the two directions of dip and cleavage crossing one another at an angle. Where igneous rocks are found alternating with sedimentary or pyroclastic rocks, dipping at considerable angles, the mountains often have great wall-like

frowning cliffs, such as those of Great End, near Scafell, and Cader Idris, or jagged, serrated peaks, which give the summits a craggy and irregular outline. In the Lake District coarse ashes and breccias form the craggy summits of Scafell, Great Gable, and the Langdale Pikes, in striking contrast to the softer outlines of the Skiddaw Slate mountains. The rounded and pillar-like outlines of the granite 'tors' of Cornwall and Devon are quite characteristic, and so also are the rounded, smooth, but bold outlines of the more lofty granite mountains (Fig. 131), although closely parallel joints occasionally form spiry crests. Gabbros, on the other hand (Fig. 174A), exhibit irregular outlines, especially when riddled with sills and dykes of different hardness, as they are in the Cuillin Hills, Skye. Mountains formed of gneisses behave very much like granites, but crystalline schists form jagged and serrated ridges, which stand out like the teeth of a saw, an effect due to the rock splitting into thin slabs along the planes of schistosity.

It is interesting to notice how each kind of rock gives rise, under similar conditions, to similar hill and valley outlines. The scenery of the Chalk of England and the North of France is everywhere the same, and, once noted, easily recognized. Mountain Limestone scenery in Derbyshire and Yorkshire is quite comparable with that of Cheddar and other districts where massive limestones occur. The terraced cliffs of dolerite in the basalts of the Inner Hebrides are repeated in the Faroe Islands. In fact, if we follow the outcrop of any bed of rock persistent over a large area, it will be found to always exhibit its own peculiar characteristics as a surface feature.

The Ages of Mountains.—In thinking of mountains we must remember that there is a limit to their life; the expression 'As old as the hills' is meaningless when one hill is compared with another. Mountains and hills are born, then attain maturity, when they exhibit their grandest and boldest forms, and finally pass away into old age and oblivion.

We have seen how mountains may be initiated by folding of the earth's crust, by sculpture from an elevated plateau, or by accumulation of débris. *From their very birth* the atmospheric agents proceed to sculpture, carve, and wear away their substance. If the elevating forces have ceased to operate, the erosive agents will get the upper hand, and begin to lower the summits. The rivers, seeking their base lines, eat back into the now mature hills, continually lowering their divides, and producing the greatest relief of hill and valley, until finally the whole structure is reduced to an almost level plain, with just enough relief upon its surface to allow the rainfall to be shed to the sea. In their later

stages, when their forms are smoothed and softened by the sheets of rock-waste accumulated on their slopes, the mountains are said to be 'subdued,' or to be in a state of old age. Old mountains are frequently much more resistant than young ones, because the cores (like heart-wood in trees) are usually tougher than the surface parts.

The collection of material, its elevation to form high ground, its sculpture and final reduction to base-level by denudation, constitute what is known as the **cycle of erosion** (Fig. 132). A second uplift would start the cycle once more.

The Alps and Himalayas are much younger than most of the mountains in the British Isles, and the elevating forces have hardly ceased to operate. On their flanks there are marine sediments, lifted thousands of feet above sea-level and tossed into fantastic forms. The Lake District and Welsh mountains are now in a late mature stage, and are becoming subdued; the cycle of erosion in their case has proceeded a long way.

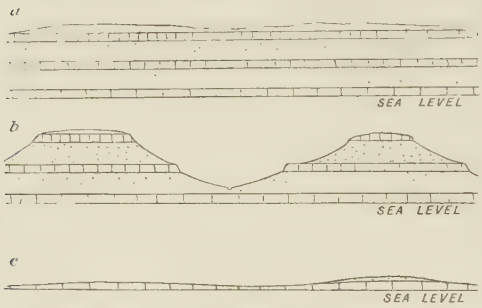


Fig. 132.—The Cycle of Erosion.

(*a*) uplift of sediments; (*b*) sculpture of sediments; (*c*) reduction of sediments to base level (a peneplain).

Buried Mountains.—During the process of erosion (especially in arid regions) it may happen that the bases of mountains are buried scores of feet deep in rock waste, filling the bottoms of the valleys and the open low ground about the foothills, so that in course of time only the very tops of the range may protrude through the mass of rubbish. If, further, the whole district is then depressed beneath sea-level, marine sediments bury up even these isolated peaks. An intensely old mountain-range of very hard volcanic rocks (p. 53) occupied the site of Charnwood Forest, Leicestershire, in Triassic times, when a desert climate prevailed. Blown sands and rock waste accumulated until they almost covered the highest peaks, which finally sank beneath the waters of a desert sea. At the present day, through elevation and denudation, the buried peaks are emerging, and the sediments being cleared out of the old valleys. The contrast between the sharp ridges of old rock and the soft swathing blanket of desert sediments is one of the charms of the district.

It is only of late years that mountains have become intimately known. Previously the summits were avoided, and only the lower passes traversed, the peaks being thought to be the haunts of spirits and demons. Mountaineers really inhabited the wild upland valleys and glens, and, living where wind, rain and storm, thunder and lightning, snow, hail, and mist, were of frequent occurrence, were often shut off from the outside world for long periods, and naturally developed a superstitious and religious nature. The bleak mountain-slopes are only fit for pasturage for sheep, goats, and cattle, or wild animals. Meadowland is limited to the small alluvial flats found here and there in the valley bottoms, and arable land to the sloping sheets of rock waste and alluvial cones on the valley-sides. Fields are often inclined at a high angle (Fig. 133), and stone walls are built to prevent the soil-creep. Tilling is done by hand, the produce being carried down to the valley by man or beast. Thus it may be easily understood that isolation, invigorating mountain-air, the strenuous life and exposure to all weathers, combine to produce those qualities of clannishness, hardiness, and self-reliance common to all mountaineers.

Similarly, men of the valleys and dales in the uplands and moorlands have developed the same qualities, softened somewhat by contact with the great centres of civilization. In North-East Yorkshire, for example, uninhabited moorlands are intersected by deep sheltered dales, with steep and often precipitous sides, cultivated and dotted with habitations (Fig. 112).

The lowland valleys, where the rivers meander freely over their flood-plains, support the densest population. Methods of transit are easy, communication between place and place is simple, and not easily dislocated by natural agencies, as it is in the upland valleys, where the effects of a heavy rain or snowstorm are not easily removed. Railway lines and good roads traverse every valley of importance ; mineral wealth is brought down from the uplands, and the surrounding lowlands support a teeming manufacturing population. These advantages of civilization, however, are offset by the disadvantages of a comfortable and enervating existence in towns, where both air and light are often poor, and indoor life unhealthy.

B. Smith.

FIG. 133.—CULTIVATION OF THE LOWER MOUNTAIN SLOPES IN THE ZERMATT VALLEY.

Notice the angle of slope of the small fields amongst the pine woods.

Mountains used to be a bar to civilization and communication between one district and another. They still are, to a great extent, but recently man has proceeded to conquer even the mountains. Whereas all railways first projected kept strictly to the river valleys, and only tunnelled where absolutely necessary, they are now not quite so restricted : the most stupendous operations are undertaken, and railways dive into the bowels of the earth or climb mountain-peaks, many of the lines being wonderful feats of engineering, in which every advantage is taken of geological structure and rock composition to make the path an easy one.

[*Photochrom Co., Ltd.*

FIG. 134.—MOUNTAINS AS BARRIERS: THE ST. GOTHARD RAILWAY ON THE ITALIAN SIDE, SHOWING THE TRACKS ENTERING AND EMERGING FROM TWO SPIRAL TUNNELS BY WHICH THE ASCENT IS MADE TO THE ST. GOTHARD TUNNEL

CHAPTER XI.

Plains and Plateaux.

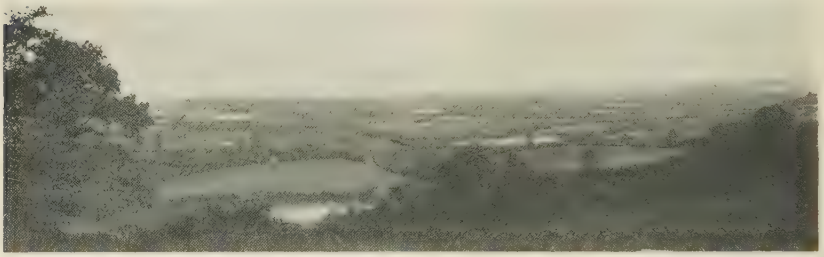
A PLATEAU or tableland is an elevated tract of land which has a fairly level surface and is not closely overshadowed by hills or mountains. A plain is a low-lying tract of nearly flat ground frequently overshadowed by ranges of hills or mountains.

Since their methods of origin are somewhat similar, they may be treated under one heading. The two terms, in fact, are loosely used; a plain, for example, is frequently diversified by small tablelands, whilst the surfaces of some plateaux might be described as plains. Plains often slope gently up from sea-level, their general surface approximating to the slope of a river valley, whilst plateaux are usually bordered by steep slopes falling rapidly away to the plains.

FIG. 135.—DIAGRAM OF A COASTAL PLAIN.
General level of plain indicated by dotted line.

Coastal Plains.—Suppose that sediments deposited on the sea bottom off a mountainous coast are gently uplifted from the water, the uplift being greatest near the mountains. The surface of the plain thus produced would be composed of the uppermost bed of the marine deposits. Rivers rising in the mountains would be extended as consequents across the plain, and sink their beds into its surface. Since rivers are most active near their head waters, and denudation would there be greatest, the higher deposits near the mountains would be quickly removed, exposing the beds beneath. Subsequents would then arise and work their way along the softer beds, developing escarpments from the harder rocks. Thus, in course of time the original gently sloping flat surface of the plain would have its general level—although diversified by escarpments and valleys—lowered nearly to the base-line of the largest consequents, and the rocks would dip seawards at a slightly greater angle than the level of the plain itself (Fig. 135).

The lowland of East-Central England is a very good example of a coastal plain, consisting of sediments (Fig. 212) accumulated upon a floor of older rocks, which rise to the surface chiefly in the west. From its highest point in the Cotswold Hills (1,093 feet) it descends to the east and south-east to near sea-level. The same plain extends to the north-east of the Pennines, but in North Yorkshire assumes the plateau form. Of the original consequent streams, the Thames is practically the only one remaining; most of the large rivers (Trent, Hunts and York Ouses) are subsequents, which have captured most of the original west-east drainage. The much-dissected escarpments of the great plain often form little plateaux, standing boldly above the small plains in the softer rocks (Fig. 136). A still younger coastal plain occupies the seaboard between Sheringham, Norfolk, and the Isle of Thanet, formed of the 'crags,' shelly and sandy deposits accumulated at a time when the coast was depressed and overridden by the North Sea waters.



H.M. Geological Survey.

FIG. 136.—THE PLAIN OF THE VALE OF BELVOIR, LEICESTERSHIRE AND NOTTINGHAMSHIRE.

Bird's-eye view from the summit of the Middle Lias escarpment, looking north-north-east. (See Fig. 129.)

Wave-cut Plains.—If the sea is actively engaged in eating its way into the land, it will be forming a *plain of marine denudation* (p. 165), thinly covered perhaps by sediment. If uplifted, this surface would be almost level, the superficial deposits upon it would be quickly swept away, and the resulting plain would bear no relation whatever to the rocks composing it. They might be thrown into folds, but the surface of the plain would be level, just as the grain in a block of wood has no relation to the surface smoothed by the carpenter's plane.

Certain so-called 'marine platforms' near the coasts of Devon, Cornwall, and South Wales, have probably been initiated in this manner, but have since been considerably smoothed or diversified by atmospheric action (Fig. 137).

Similarly by greater and more extensive uplifts either of the above types of plain—or a combination of the two—become plateaux.

Cycle of Erosion.—As the plateau rises, it develops a drainage system, which, when the elevating forces come to rest, begins to break it up and reduce it piecemeal. A young level-topped plateau becomes deeply scored by watercourses in ravine-like valleys, and split up into isolated hills, the shapes of which depend upon the rock structure. This is a partially dissected plateau. When the valley floors are widened and the walls opened out, a further stage is reached; small remnants only are now left, and the plateau is said to be maturely dissected. Given time, the rivers and atmospheric agents would probably reduce the whole

H.M. Geological Survey.

FIG. 137.—COAST OF PEMBROKESHIRE NEAR ST. GOWAN'S HEAD.

The flat surface is probably a plain of marine erosion.

plateau to a low-lying plain, with just sufficient relief to shed the water falling on it. Such is a *plain of atmospheric denudation*—an almost level surface (*peneplain*)—and with it the 'cycle of erosion' (p. 110) is complete. Coastal plains and marine platforms will be similarly brought low, but in all cases the resulting plain, on re-elevation, would again go through the same process of dissection and reduction.

A good example of a dissected plateau, formed by uplift of marine sediments, is the Carboniferous plateau or Pennine upland of West Yorkshire and Derbyshire, from which the terraced heights of Ingleborough, Whernside, and the Peak have been carved. The Cleveland Hills also form a tableland in process of dissection (p. 91). The Grampian Highlands (p. 174) consist of highly folded metamorphic

rocks, long ago planed to an almost level surface. The original surface sloped from north-west to south-east, where it falls abruptly to the Central Valley. It is now trenched by deep glens, isolating mountains, the highest of which almost reach the level of the old plateau (Fig. 138).

Another example in which highly folded rocks (slates and shales) were planed down, and subsequently uplifted to form a plateau, is provided by the Southern Uplands. The north-eastern portion is more perfect than that in the south-west, which is more highly dissected.

River Plains.—The surface of a plain of atmospheric denudation is levelled off both by reduction of the high land and by filling up of the low

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FIG. 138.—THE GRAMPIAN HIGHLANDS.

A deeply dissected plateau.

ground with rock waste. River plains, gently sloping seawards, are caused by lateral corrasion of the streams during maturity and old age, and by deposit of alluvium (Fig. 139). Along the course of any river small local plains in the softer rocks may alternate with stretches of gorge, waterfall, and rapid in the harder rocks. Large rivers naturally have the largest flood-plains. River-borne sediment is also responsible for delta-plains in lake or sea and for the silted-up flats marking the sites of former lakes or estuaries.

H. H. Swinnerton.

FIG. 139.—A RIVER PLAIN.

The Vale of the Trent from Malkin Hill, near Radcliffe-on-Trent.

Plains of Marine Alluvium.—The Fenland, once a deep gulf—running inland through a gap in the chalk escarpment between Norfolk and Lincolnshire—which had been deepened by ice action during the Glacial Period, has been to a great extent built up by sea-borne silt deposited at the slack of high-water. The Wash is the remaining part of this great bay, and is gradually becoming shallower; at the south end silting up is still in progress. The peat for which the district is noted, and which has now ceased to be formed, is a marsh vegetation, consisting chiefly of the decomposed remains of aquatic herbaceous plants, which

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FIG. 140.—THE RIVER TAY WINDING THROUGH THE 'CARSE' AT STIRLING.

View from the Abbey Craig.

grew upon the silt and clays cast up beyond the level of high tides. Slight oscillations in the level of the land from time to time also led to the growth and destruction of forests. There is a certain amount of river-borne sediment added to the surface also, but the plain is really a sea-formed flat built up by aggregation. Similarly, large parts of the great alluvial plain between York and Gainsborough, in the Humber basin, were formed by deposits of silt and mud (warp) laid down at high tide, the sediment being partly furnished by rivers, and partly by drift into the bay from the coast.

Other sea-formed plains have been reclaimed by embankments, and are now below high-tide level, but are being slowly raised by inland floods (Fig. 200).

Slight uplifts account for the raised-beach plains of Scotland, and the fertile 'carses' of marine alluvium, like those of Gowrie or Stirling (Fig. 140).

Plains and plateaux are formed by the outpouring of basaltic **lavas,** such as those of Antrim and the Western Isles (Fig. 141), the Snake River plains, and the Deccan. We might also mention the plains and plateaux of floating and inland **ice**, the latter resting sometimes upon an uneven rock floor.

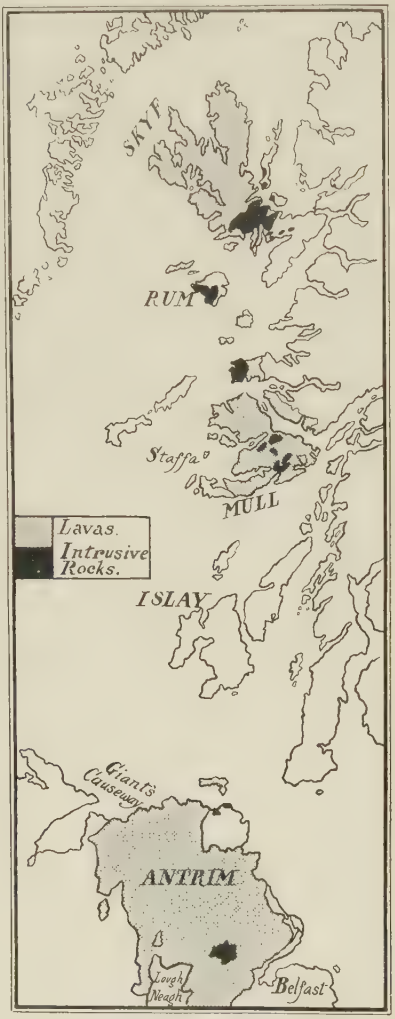


FIG. 141.—DISTRIBUTION OF THE PLATEAU BASALTS OF ANTRIM AND THE WESTERN ISLES. (After Geikie.)

Plains depend for their climate and fertility upon latitude, rock composition, and distance from the sea. Those in the temperate regions, and the great tracts of grassland, furnish some of the most profitable agricultural belts, but desert areas, properly irrigated, are intensely fertile, because the soil has not been leached of its soluble constituents during weathering. High-level plains and little-dissected plateaux will, as regards temperature, be influenced by elevation, and the climate will be alike over large areas. The low-lying seaboard of Africa is marshy and unhealthy when compared with the high tablelands of the interior. Similarly, the plateaux of the South American Cordilleras compare most favourably with the sickly coast regions and river plains. The great elevated mountainous plateaux of Central Asia breed hardy mountaineers, inhabiting the fertile valleys; high dissected plateaux, in fact, experience much the same conditions of climate as the mountains; soil also is thin, and the struggle for existence keen. The greater

fertility and more equable climate of the plains have an enervating effect upon their inhabitants. Alternating rocks and soils of coastal plains account for the differences

A. T. Metcalfe.

Fig. 142.—Part of the Plateau of Tertiary Basalt capping Jurassic Rocks (white), Carsaig, Mull.

Notice basalt screes at foot of cliff.

of vegetation and industries. Villages are clustered along the water-bearing beds, or along the belts rich in agricultural land or in rocks of economic value.

CHAPTER XII.

Snow, Ice, and Glaciers.

Those districts, whether high mountains situated near the equator—*e.g.*, at well over 15,000 feet* in New Guinea—or low ground in high latitudes, where snow lies all the year round, are said to be in the region of the 'eternal snows.' Looking at a high mountain-range from a distance, most of the snow will be seen to lie above a certain fairly definite line, which appears to be ruled across the chain. In sheltered places some patches appear below this limit, and some exposed rock lies above it, but on the whole this so-called 'snow-line' divides the eternal snows above from the bare mountain-slopes below. The line is fixed in summer, for only those snows which survive from winter to winter can rightly be termed everlasting, their presence implying that the snow shed in the winter is greater in amount than that melted in the summer. This

* Glaciers descend to this level.

being the case, the snow would increase year by year and the snow-line move to a lower level if the disposal of the excess were not nicely adjusted to the needs of the particular district. (See also p. 28.)

Mountains rid themselves of their excess of snow in three ways: by (1) evaporation; (2) avalanches; (3) glaciers.

(1) Just as water-vapour can pass directly to snow, so snow can pass directly to water-vapour without showing signs of melting. Snow often disappears slowly by evaporation during frosty weather.

(2) In early spring the high mountains are constantly echoing to the roar of the avalanche, which not only carries down snow and ice, but also huge rocks,* stones, and weathered material. About one-third of the annual snowfall of the St. Gothard Range is removed in this way, and many an upland village has its plantation of pines on the slopes behind it to ward off the danger.

H. Speyer.

FIG. 143.—MOUNTAIN SWEPT BY AVALANCHES. (Dent d'Herens.)

(3) **Alpine Valley Glaciers.**—Glaciers are born in the snowfields which lie on the flatter parts of the high ground, on the passes, and on the slopes between the peaks. The snow at the surface of a field is called *névé*, or *firn*, accumulating layer by layer with each winter's fall, and each layer may be separated from that below by a band of dirt. Under pressure of the upper layers the lower parts of the *névé* begin to move slowly down the valleys leading from the snow-fields, and become compacted into glacier ice, just as a snowball, if squeezed very hard, becomes a mass of ice.

Glaciers may be compared with rivers in many respects, for the snow-shed may bear minor *firns* whose glaciers flow down smaller valleys as tributaries to the main stream. The Gorner Glacier, near Zermatt, for example, is fed by many tributaries descending from the Swiss-Italian frontier (Fig. 148).

* Tyndall writes: 'Immediately afterwards a peal like that of thunder shook the air, and right in front of us an avalanche darted down the brown cliffs . . . carrying with it the débris of the rocks over which it passed, until it finally lay a mass of sullied rubbish at the base of the incline: the whole surface of the Talèfre [glacier] is thus soiled.'

Where there is a steep fall in the valley-floor, there will be an ice-fall or cascade—analogous to a waterfall—where the ice becomes fissured and slides downwards in long irregular blocks, the fissures being called 'crevasses.' The most important crevasses* are (*a*) transverse—crossing the glacier from side to side, as above ; (*b*) longitudinal—running lengthwise down the glacier, and usually formed where the valley widens and the ice expands.

If an ice-fall is very irregular, the transverse crevassses are crossed obliquely by others, the whole forming a jumble of ice segments which, aided by melting due to the sun, gives rise to a tossing sea of pinnacles known as 'séracs' (Fig. 145). Crevasses often become sealed up after the ice has passed the fall, but may still be traced by the dirt they collected.

Glaciers move slowly down their valleys, some exceedingly slowly, whilst others cover several feet per annum; and, like rivers, the centre of the stream moves faster than the sides, and the surface layers faster than those below. Just as a line of stakes across a glacier slowly assumes a curved form, so also the transverse crevasses become curved because the centre moves fastest.

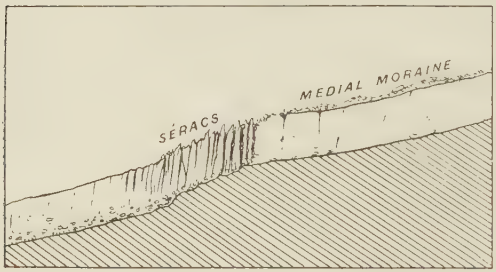


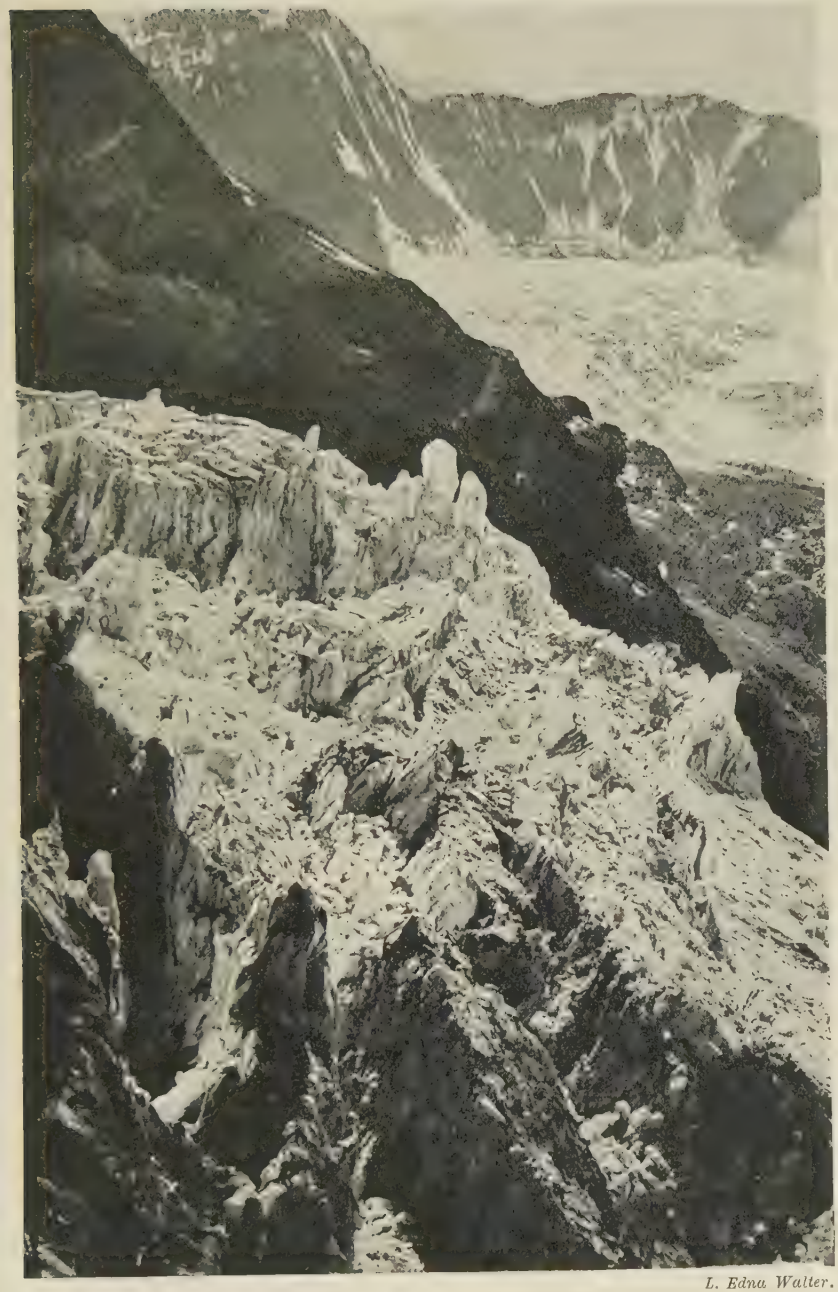
Fig. 144.—Diagram of an Ice-Fall.

A glacier's termination is called its 'snout,' and is situated at a point where the loss due to melting is exactly balanced by the supply descending from above. Should the supply be in excess, the snout will advance ; if less than usual, it will retreat. Some of the Spitzbergen and Greenland glaciers of Alpine type are advancing ; their snouts, instead of being tapering through rapid melting, end in a vertical cliff, known as a 'Chinese Wall.'

Glaciers **transport** rock waste from high to lower levels, carrying it (*a*) on the ice ; (*b*) within the ice : (*c*) in the sole of the glacier.

(*a*) As the ice travels past the steep valley walls, scree-shoots shower upon it rocks detached by atmospheric (frost) action, and avalanches

* A special type of crevasse, a frequent obstacle to mountaineers, is the *bergschrund*, formed where the upper end of a snowfield has broken away from the steep mountain-side.

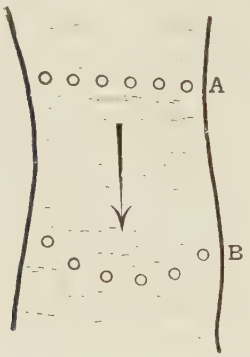


L. Edna Walter.

Fig. 145.—Séracs on the Unter Grindelwald Glacier.

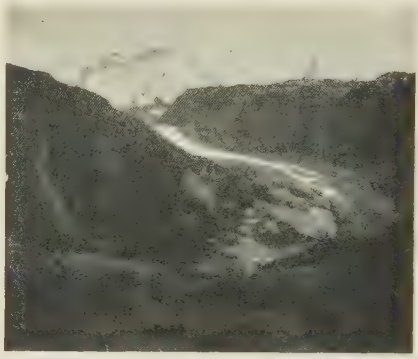
sweep talus from the slopes. Thus the load is being constantly added to, so that in course of time continuous piles of rubbish collect on the glacier's sides and move along with it. These **lateral moraines*** are usually sharply ridged, because the blocks, many of which are of tremendous size, fall from the top and lie on either side at the angle of rest.

When two glaciers unite, the lateral moraines at the point of junction combine to form a **central moraine**; therefore, when a glacier has several tributaries, it also has many central moraines which, from a distance, look like cart-tracks on a snowy road (Fig. 149). In the lower reaches moraines spread laterally, because the sun melts the exposed surface of the glacier between them, forming hollows into which the blocks roll side-



A = Stakes driven into ice
B = Stakes some days after

FIG. 146.—MOVEMENT OF A GLACIER.



B. Smith.

FIG. 147.—THE GORNER GLACIER NEAR ITS SNOUT.

Notice the smoothed rocks, which it once covered, upon its right.

ways. In this manner the whole lower end may be covered with débris. Similarly, large flat rocks† are apt to become poised upon pedestals of ice which they have shielded from the sun's rays, and form 'glacier tables.' These moraines are deposited at the snout as a **terminal moraine.**

(*b*) Some rock waste is incorporated in the body of the glacier, for example, at ice-falls, where the moraines may be engulfed. This is called **englacial** material.

(*c*) The **ground moraine** carried in the sole of the glacier is perhaps the most important. Rocks falling down crevasses are dragged along and

* Lateral moraines are often best developed upon the inner or concave curves of glaciers where the ice is slack and deposits some of the rock waste it is carrying.

† Small isolated stones become heated and sink in the ice.

used by the ice to scrape, file away, and pluck at its rock bed. Not only does it grind the latter to fine rock powder, it also causes the stones themselves (its tools) to be smoothed, polished, and scratched. Hence glaciers, like rivers, *corrade* their beds.

The **drainage** of a glacier, due to melting, is sometimes intricate. Small streams run in gorge-like channels in the surface, and obey most of the laws of river development, but occasionally plunge down crevasses, taking on a gyratory motion. The swirling waters carrying down stones wear out, or lick out, cylindrical shafts (*moulins*), which may persist even after the crevasse which gave them birth is sealed up. Some reach the bottom of the glacier and drill potholes in the rock bed, forming the 'glacier mills' which are found where ancient glaciers are known to have rested. The falling water joins the subglacial drainage, which usually concentrates in one channel, and emerges at the snout (frequently from an ice-cave) as a milky-white stream full of gritty silt and mud—a most formidable corrasive agent, capable of cutting the remarkably steep and narrow gorges situated below the snouts of many Alpine glaciers. The rivers also spread out morainic matter as fans of boulders, gravel, sand, and silt.

B. Smith.

FIG. 148.—OLD LATERAL MORAINE OF THE FINDELN GLACIER, ZERMATT.

The recent moraines of the shrunken glacier are seen on the right.

Corrie Glaciers.—A 'corrie' is a hanging valley with a head consisting of an amphitheatre of precipitous cliffs forming a 'cirque.' They are frequently occupied by glaciers, and since no true 'corries' are found in regions which have never been glaciated, the cliff-like cirque is supposed to be due to the plucking away of rock by the ice at the bottom of the *bergschrund*.

Piedmont Glaciers.—When several valley glaciers unite on the plains, they form a piedmont glacier. In Alaska the Muir glacier is made up of several tributary valley glaciers, and the piedmont on the whole is retreating, although there are occasional local advances. At

FIG. 149.—THE GORNER GLACIER, ZERMATT

L. Edna Walter

Composed of several tributaries separated from each other by the central moraine.

one time it was 2,000 feet thicker than at present. The Malaspina Glacier,* near Mount St. Elias, with an area of 1,500 square miles and an elevation of 1,500 feet, is formed of three lobes, which unite on the plain. Moraines stream from the mountain spurs to the north, uniting on the southern portion, which is fringed with a forest 4 to 5 miles wide.

Ice Sheets—variously referred to as ice caps, continental ice or glaciers, and inland ice—are developed where conditions are suitable for the widespread accumulation of snow; at the present day in polar regions.

Greenland's ice sheet forms a gently sloping plateau which covers everything inland† and falls gently towards the coast, where mountain-tops project through it like islands‡; after which it descends seawards as glacial tongues through the rocky fjords of the coast. Scott and Shackleton have shown that South Victoria Land is similarly covered by a great ice sheet fringed by glaciers which traverse deep rocky valleys to the coast, sometimes forming piedmonts on the low ground. The Great Ice Barrier, composed of snow and ice, is apparently afloat at its seaward end. It is partly fed by glaciers, but is mostly formed of snow accumulated on its surface many miles from the sea; the bergs given off by it float much more lightly than true ice-bergs. It is now retreating, but in the past probably increased in size by accumulation of snow upon its surface.

B. Smith.

FIG. 150.—A GLACIER TABLE ON ONE OF THE CENTRAL MORAINES OF THE GORNER GLACIER.

Icebergs.—When a glacier enters the sea, its snout ploughs along the sea bed until the buoyancy of the water, aided by the tides, causes it to crevasse and yield up masses of ice, which rise to the surface and float away as bergs. Those from true glaciers float with about one-ninth

* This glacier has recently advanced. (See Flint, p. 58.)

† Surface moraines are absent inland.

‡ Such islands are called 'nunataks.' Where the ice is thin, on the col between two nunataks, the ground moraine often appears at the surface. Thus the bottom layers of the ice have *moved uphill*, carrying débris with them. (See The Work of a Glacier, p. 128.)

of their bulk above water, but the larger tabular bergs of the Barrier expose quite one-sixth of their mass. Icebergs are great transporters of rock, since they are loaded with moraine, which they drop as they melt.

Sea Ice.—In high latitudes the sea water freezes during the winter months (to a depth of some 8 feet), but in summer breaks up and floats away to form the 'pack ice' encountered by ships in polar regions. Spray from the sea also freezes and fringes the land as 'ice foot,' which protects the beach when the tides are small, but acts as a powerful eroding agent if broken up and driven on shore by storms.

Fig. 151.—View showing the Formation of Icebergs from a Glacier.

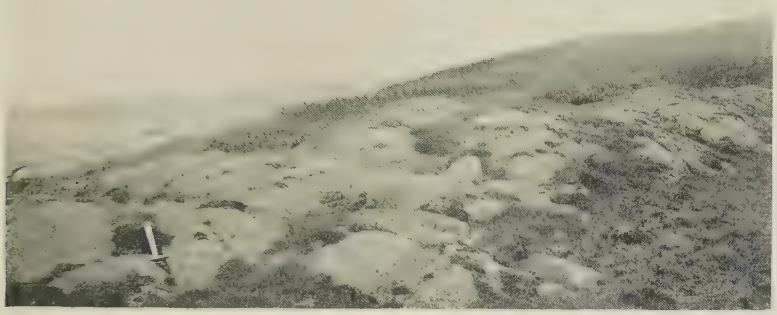
The work of a glacier, like that of a river, includes *erosion*, *transport*, and *deposition*.

Soft, unconsolidated rock and rock waste is removed and transported as ground moraine ; harder rocks are polished, grooved, worn down, and even plucked away ; stones and boulders in the ice are smoothed, polished, and striated by contact with one another and the hard rocks in the glacier bed. Much transported material is englacial, and angular blocks and huge boulders are sometimes carried for miles in the surface moraines. Rocks may be carried from low to high levels, as well as from high to low levels. When glaciers and ice sheets retreat, or cease to work, they deposit all their morainic matter, and the débris sorted by the action of running water—fluvio-glacial material.

Although most of the above phenomena can be observed near existing ice sheets and glaciers, it is unnecessary to go far to study some of the characteristic features due to glaciation, for at a comparatively recent

geological period (p. 173) parts of the northern hemisphere were invaded by ice. The climate, of typical severity when the London Clay was formed, gradually cooled until the growth of glaciers became possible. In Great Britain and Ireland signs of this former glaciation are very abundant.

Erosion is shown by the polished and striated rocks (Fig. 152) that lay in the path of the stone-laden ice : long grooves were formed parallel



E. L. Guilford.

FIG. 152.—POLISHED AND STRIATED ROCKS (ROCHES MOUTONNÉES) NEAR MILLOM, LANCASHIRE.

to the direction of movement. When the ice met a projecting knob of rock, it ground it down and polished it smooth on the impact face, but left it untouched or rendered it jagged by plucking pieces away (if well jointed) on the lee side—a process resulting in the production of rocks of characteristic outline known as *roches moutonnées*.*

A normal river valley has its tributaries so adjusted that they meet the main valley at its own level. In glaciated regions, however, hanging valleys are extremely common (Fig. 154), in many cases obviously the result of glaciation. On looking up a normal river valley the rock spurs on either side are seen to overlap. In a well-glaciated valley the spurs do not overlap, because they are cut away, and the main valley has been deepened, leaving a U-shaped

FIG. 153.—DIAGRAM OF ROCHES MOUTONNÉES.

* A name probably suggested by their resemblance to sheep's backs.

trough (p. 99) with precipitous walls, upon which the mouths of the side valleys open at a high level (Fig. 156). A mature glacier, unlike a mature river, fills the whole valley, and we must compare its trough with the bed of the river. Although the surfaces of the tributary glaciers meet the main glacier at the level of its surface, their smaller bulk and excavating powers are such that their floors are at much shallower depths than that of the trunk glacier, and therefore mouth above it. In these *overdeepened valleys* the frost-riven crags which stood above the ice limit are in striking

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FIG. 154.—A HANGING VALLEY, ONCE OCCUPIED BY A CORRIE GLACIER.

Formed in Torridon Sandstone, Beinn Bhàn or Applecross, Ross-shire.

H.M. Geological Survey.

FIG. 155.—OVERDEEPENED VALLEY WITH SPURS CUT AWAY, DUE TO GLACIATION.

In foreground, silted-up glacial lake. Gleann Mòr, Ross-shire.

contrast to the smoothed rocks of the glacial troughs. Examples are common in the mountain districts of Great Britain and Ireland. In

Skye the details of relief in mountain and valley are directly due to ice and frost: rocks of different degrees of hardness have been carved and smoothed to a common level, and the valleys have been widened, deepened, and straightened. The lateral valleys are hanging, their heads being developed into corries, with cirques, in which there are sometimes small rock basins occupied by tarns. True rock basins (*i.e.*, hollows in the solid rocks) are evidences of the erosive action of ice; they abound in Scotland, the Hebrides, and all regions once subjected to the grinding action of glaciers (Figs. 174 and 174A); and, on the contrary, valley lakes are wonderfully scarce in all unglaciated regions.

B. Smith.

FIG. 156.—THE FINDELN GLACIER, STREAM, AND HANGING VALLEY, NEAR ZERMATT.

Transport and Deposition. — The *moraines* of the old glaciers are often as fresh-looking and striking in appearance as some of those near the shrinking Alpine glaciers. Terminal moraines form moundy ridges of semicircular shape; the two in the Vale of York, left by a glacier which rested during its retreat to the North, are good examples, whilst that of the North Sea ice crosses part of Flamborough Head as a series of gravelly mounds. Small terminal moraines in the upland corries often enclosed, or still enclose, lakelets and tarns; and lateral moraines appear as long, winding embankments, now covered with turf, bracken, and heather, but consisting of tumultuous heaps of angular or partly smoothed and scratched boulders, with rock rubbish of all grades of size. *Perched blocks* are boulders once carried upon the surface of the ice, but gently deposited upon the rocks beneath when it melted. It thus happens that some are delicately balanced upon *roches moutonnées*, high up on the valley sides. The boulders have frequently travelled miles from their place of origin, and are of a very different type to the rocks upon which they now lie. Such wanderers, or 'erratics,' are thickly strewn over many parts of the country, and when trails of them are found they are

useful guides to judging the direction of movement of the glaciers which carried them.

FIG. 157.—A VALLEY SYSTEM OCCUPIED BY A GLACIER AND TRIBUTARIES. (After W. M. Davis.)

FIG. 158.—THE SAME AFTER DISAPPEARANCE OF THE ICE, SHOWING OVERDEEPENED RIVER VALLEY, HANGING TRIBUTARIES, CIRQUES, AND ROCK-BASINS.

FIG. 159.—ERRATICS IN A HIGHLAND GLEN, WEST OF SCOTLAND.

Boulder Clays are the most extensive deposits due to ice action, and represent the ground-moraines of glaciers. They vary in composition, thickness, and colour, according to the structure and texture of the rocks

crossed by the ice, and its power to remove them. A typical boulder clay (Scottish 'till') is a stiff clay containing an assortment of boulders of all sizes stuck in it at all angles. The boulders are partly smoothed and rounded, partly angular (subangular), and the polished sides are often beautifully scratched by being ground against other stones. When a glacier has crossed the outcrop of a sandstone the clay is sandy. A red or blue clay gives rise to a stiff purple or blue boulder clay, each variety being dragged some distance over the outcrop of the next rock. These clays occasionally contain boulders of enormous size. Huge chalk erratics up to 100 yards in length, picked up bodily by the ice and incorporated in its ground-moraine, are now exposed in the Cromer and Sheringham cliffs, and elsewhere many great masses of Lincolnshire Limestone have been similarly moved.

E. L. Guilford.

Fig. 160.—Subangular, Smoothed, and Striated Boulder (1 Foot Long) from Boulder Clay, Whitbeck, Cumberland.

The boulder clay has sometimes filled up old valleys (p. 100) and diverted the drainage, and at other times has been smoothed out into long swelling ridges (*whalebacks* or

Fig. 161.—Drumlins. (After McHenry.)
South of Craigavad Station, Belfast.

drumlins) running parallel to the direction of ice movement (Fig. 161). Long gravelly ridges (called 'eskers') represent the infilling material of

englacial or subglacial drainage channels, which have now lost their icy retaining walls.

Boulder clay and moraines have often interfered with the drainage, and added to the number of lakes so characteristic of a glaciated district.

The Invasion of Britain by Ice.—The path of an old glacier is determined by noting (i.) the trend of the moraines ; (ii.) the distribution and composition of the boulder clay, and the trend of drumlins ; (iii.) the rocks of which the erratics are

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FIG. 162.—MORAINES : LATERAL AND TERMINAL.

The loch in foreground is dammed by cones of débris. Lochan an Iasgaich, Ross-shire.

composed, and the directions of trails of the same ; (iv.) the directions of striations on polished rock surfaces and *roches moutonnées ;* (v.) crags of rock, with tails of boulder clay behind them.

The directions of movement of the principal ice sheets and glaciers are shown in the accompanying map (Fig. 163). It is improbable that they all reached their maximum at the same time ; the Irish Sea basin was invaded, and filled by snow and ice most completely after the North Sea ice had reached its maximum. Some of the glaciers were piedmonts —that of the North of England, for example, where certain hill-tops seem to have escaped glaciation, even though surrounded by ice sheets. Parts of the Lincolnshire and Yorkshire Wolds, Flamborough Head, the Cleveland Hills, the Yorkshire Moors, and the Pennines also escaped. In other

cases the highest mountain-tops, such as Ben Nevis and Schiehallion, were covered to their summits; the Cuillin Hills (Skye) were completely buried, and ice has left its mark on some of the tallest peaks in North Wales and the Lake District. The

FIG. 163.—GLACIATION OF THE BRITISH ISLES.

most extensive sheet of boulder clay is that of the eastern counties, known as the Great Chalky Boulder Clay, from the amount of chalk in its composition. It is underlain and sometimes interbedded with fluvio-glacial sands and gravels.

CHAPTER XIII.

Lakes.

ANY hollow capable of holding water may give rise to a lake.

Lakes are of two kinds:

1. Those due to a barrier holding up the natural drainage.
2. Those lying in hollows in the solid rocks—called 'rock basins.'

1. **Barrier Lakes.**—(*a*) If a glacier crosses the mouth of a side valley down which a stream is flowing, it may dam up the waters and

form a lake. A good example is the beautiful Märjelen See, held up in a lateral valley by the great Aletch glacier of Switzerland.

Such lakes were formed on a much larger scale in various parts of Britain during the Ice Age. The famous 'parallel roads' of Glen Roy, in Inverness, are the wave-cut shore-lines of a great lake, whose waters were impounded and held at three consecutive levels by ice to the west.

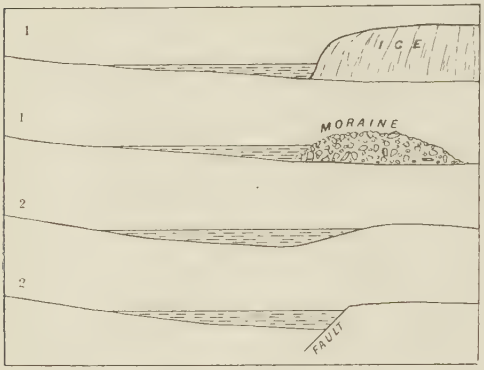


Fig. 164.—Diagram of 1, 1, Barrier Lakes; 2, 2, Rock Basins.

Similar lakes were held up in Eskdale (Cleveland) and the Vale of Pickering, and wherever the ice was in contact with high land down which water was draining to the ice front (Fig. 165).

Other lakes are found on and in the ice of glaciers, or at the extremity of the rocky spur where two tributaries meet. They occur where glacial deposits are irregularly dumped; thousands of meres and tarns owe their existence to this cause. The most striking effects occur where the moraine of an ancient glacier crosses a valley mouth. Windermere is formed in this way; the old outlet of the valley was filled up with glacial drift, and the waters rose behind the barrier until the height of the present outlet was reached (Fig. 176).

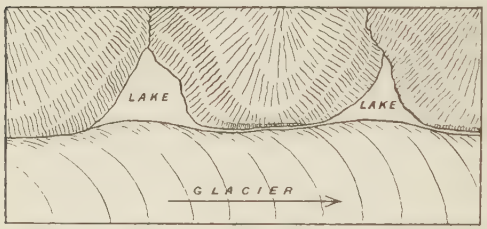


Fig. 165.—Glacier holding up Land Drainage.

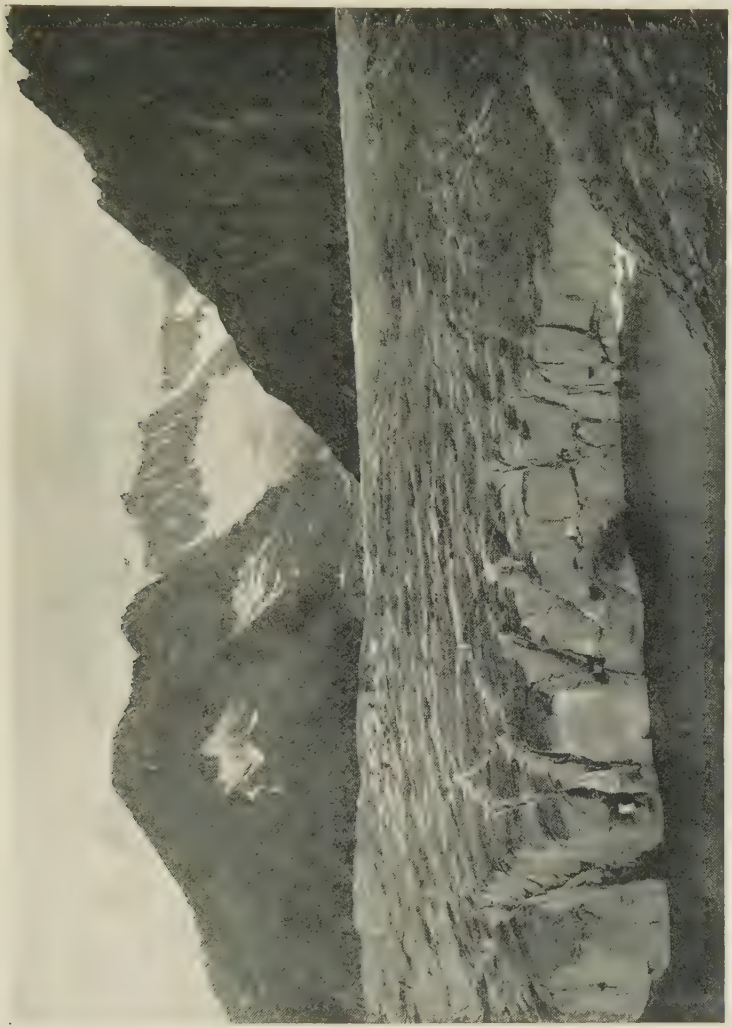
(*b*) Landslips, screes, lava-flows, and sometimes even volcanoes may obstruct drainage and give rise to lakes.

(*c*) Alluvial torrential cones of side streams sometimes hold up the waters of the main stream and form lakes, which may be fairly large, especially if the main stream has been beheaded. Again, the alluvium of the main stream may stop up the waters of the side valleys.

Deserted meanders give rise to crescentic 'oxbow' lakes, or cut-offs, which are fairly common and of considerable size on large river plains.

(*d*) Sand and shingle drifted along the coast may prevent rivers from directly reaching the sea, and hold up the fresh waters behind a barrier as a lake.

The Norfolk Broads district was once a series of estuaries, which have been cut off from the sea by sand and shingle bars, and are now silting up from within. The



L. Edwin Watt r.

Fig. 166.—The Aletch Glacier holding up the Märjelen See.

coastal drift is from north to south, and the rivers have dropped their sediment on the inner sides of the bars as well as at the heads of their estuaries. Branches of the estuaries are now left as 'broads,' the remaining area is filled with silt, increased and compacted by marsh vegetation (Fig. 170).

Beach deposit cast up by the sea frequently ponds up inland drainage. Many of the Étangs of the French Mediterranean and Atlantic coasts

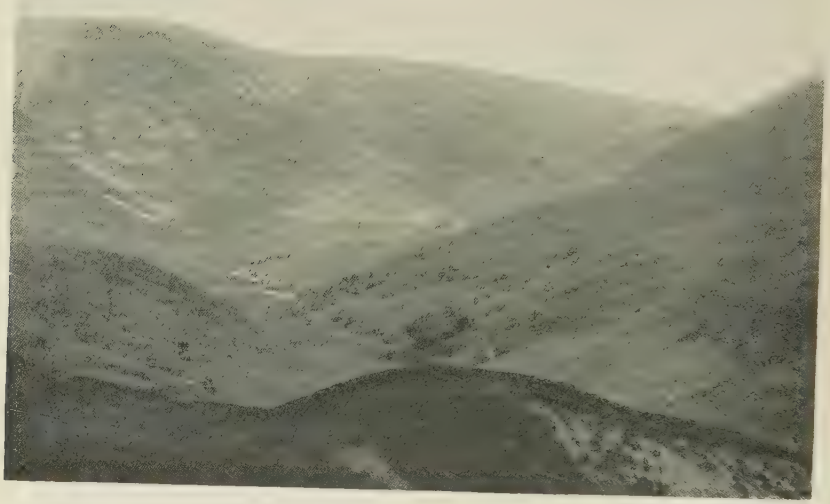


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Fig. 167.—The Parallel Roads of Glen Roy.

The shore lines are at 856, 1065, and 1149 feet above sea-level.

are formed in this way. In England there are smaller examples. Other pools are formed by barriers of blown sand ; the Great Pool of Scilly has dune sands at both ends (Fig. 172).

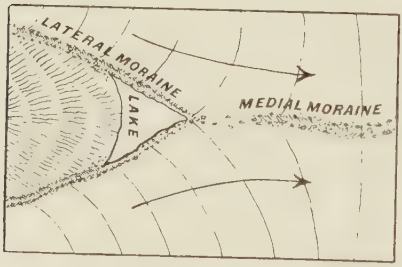

Fig. 168.—Lake at Meeting-Point of Two Tributary Glaciers.

2. **Rock Basins.**—(*a*) Some of these are due to movements of the earth's crust—either folding or faulting. Amongst them are lakes of the Aralo-Caspian area (cut off from the sea by gentle warping of the earth's crust) and of the Great Basin region of North America. The Dead Sea and some of the African Lakes occupy depressions in the floor of the Great Rift Valley (Fig. 173).

In the Great Basin region (Utah) warping, accompanied by faulting, has been proved ; and warping has also occurred around the Canadian

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FIG. 169.—MORAINE-DAMMED LOCHAN, SKYE.

Moraine in middle distance. Mountains on left composed of granite; on right of gabbro. Loch an Eilean, Sligachan, Skye.

Lakes, whose existence, however, is partly due to glacial interference. Portions, at any rate, of some of the Swiss and Italian Lakes were formed by folding (in some cases the bottoms lie below sea-level), the remainder date from the Ice Age.

Unless the earth-movements are large, and take place quickly, we should expect the rivers to keep their courses open, and not be ponded up. Small lakes, in fact, have been formed during earthquakes by the production of a fault-scarp crossing the valley.

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FIG. 170.—ORMESBY BROAD, NORFOLK.

Notice the vegetation.

(*b*) Many examples of ice-eroded hollows are recorded from Scotland, in which rock *in situ* is found all round the lake, and there is no question whatever of a morainic barrier.

Where the valleys were constricted and the ice piled itself up thickly, the erosion was greatest and the lake is deepest. Again, where belts of soft or shattered rock cross the lake, the floor was scoured most deeply.

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FIG. 171.—THE SWANS POOL, FALMOUTH.

Lake formed by the natural dam of a beach piled across the front of the valley. Cliff and wave-cut platform in foreground.

H.M. Geological Survey.

FIG. 172.—THE GREAT POOL, TRESCO, SCILLY.

A fresh-water pool. The sea is kept out at both ends by sand-dunes. Those at south-east end only seen in the photograph.

Loch Lomond, 600 feet deep, is a good example. It shows signs of glaciation from end to end, and has on its flanks several fine hanging valleys (*e.g.*, Inversnaid) due to overdeepening of the main valley, now occupied by the lake. The Outer

Hebrides are thickly covered with lakelets, many of which are in basins ground from the gneissic rock. In some cases there is a combination of rock basin and barrier.

Corrie lakes are formed behind the terminal moraines of corrie glaciers or by screes, but others are true ice-formed rock basins (Fig. 174).

(*c*) Crater lakes, usually occupying calderas, occur in districts of extinct volcanoes, such as the Eifel, Central Italy, and the Auvergne. The crater of La Soufrière, St. Vincent, supposed to be extinct before the eruptions of 1902, enclosed a lake which has again appeared since activity ceased. In many South American eruptions immense

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FIG. 173.—A ROCK BASIN.

View across the Dead Sea towards the faulted escarpment of the Syrian Plateau.

quantities of dead fish, which inhabited the crater lakes, have been swept down with the escaping torrents of water. No true crater lakes occur in Great Britain, with the possible exception of a small but deep tarn in the volcanic neck of S. Airde Beinne, near Tobermory, Mull.

(*d*) Water, acting either mechanically or chemically, is responsible for the formation of rock-basins. Below waterfalls the swirling waters often form a large basin, such as that of the Grand Coulee, Washington, which lies below an abandoned fall 200 feet in height.

Percolating waters sometimes dissolve irregular masses of salts, such as those of Cheshire, and allow the earth above to subside and form a

hollow. Many of the Cheshire meres were thus produced. Solution of limestone gives rise to the collapse of cavern roofs, so that the subterranean exit of the waters is blocked up and the unroofed cavern becomes filled with water. Similarly, a swallow-hole at the end of a valley may become blocked up.

Shore Lines.—The outlines of lakes are varied. Those occupying river-valleys have outlines approximating to the contour-lines in the valley system, with **V**-shaped branches up the side valleys. In many

G. P. Abraham.

Fig. 174.—Glaslyn, Snowdon: an Ice-Eroded Rock Basin.

Notice the glaciated rocks on both banks. Outlet to left of picture.

instances, however, these branches are replaced by flat stretches of alluvium (Fig. 83) deposited by the tributary streams. Long and narrow lakes usually lie in steep-sided valleys; rounder lakes, with the exception of those in craters, occupy relatively shallower and broader valleys (Fig. 176).

Most lakes have remarkably flat bottoms, as may be expected when the lake is a drowned river-valley. When great isolated deeps are found, the lake usually originated in some other manner: in ice-eroded rock

basins, for example, where shattered rock underlies the lake (Loch Vennachar), or where the shores are constricted and the ice piled up (Loch Coruisk) such deeps occur.

Waves attack the shore-lines of lakes in a manner similar to those of the sea (Chapter XIV.), and may cut a similar cliff and platform, upon which beach material—pebbles and shingle—accumulates, sometimes making the shelf-like feature wider. The shore-line tends to become simplified, the salient headlands are cut back, and shingle is swept into the bays, forming beautifully smooth curves.

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FIG. 174A.—LOCH CORUISK, SKYE.
An ice-eroded rock basin.

Lakes are only temporary features, and indicate a youthful drainage. No sooner is one formed than its destruction is commenced, either by filling up the hollow or by depriving it of water. The **filling up** is due to (1) avalanches; (2) vegetation in the bottom of the lake (Fig. 170); (3) alluvium-lacustrine and fluviatile.

The different kinds of alluvium are shown in Fig. 177, where *d* is a very fine fluviatile mud, which spreads over all the floor and causes, or accentuates, its flatness. In Buttermere there is a plain 400 yards × 200 yards of nearly uniform slope from end to end.

Deltaic deposits, *c*, found either at the head of a lake or at the sides, where there are tributaries, are similar to those found in the sea, but their fronts slope at greater angles (about 1 in 3), and the composition is more varied in grade of material.

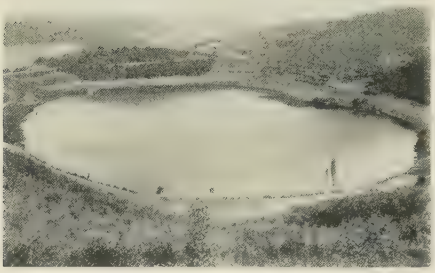

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FIG. 175.—GMUNDER MAAR, EIFEL.

A crater lake (in Caldera).

When water enters a lake, its velocity is checked, and consequently some of the load is dropped, the coarsest first, the finest being carried farthest. In plan a delta is somewhat like an equilateral triangle (Greek Δ, whence its name), but presenting a convex base to the lake waters. In section it consists of three parts, as shown in Fig. 179, where deposit 3 is similar to *d* in the previous diagrammatic section. As

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FIG. 176.—WINDERMERE.

Notice the long narrow shape of the lake.

the delta is built up and pushed forward into the lake, the alluvium of the stream, 1, which follows one or more courses through the delta.

thickens and extends upon its surface. If the stream enters the head of a narrow lake from a flood-plain, the delta-front is usually broader and straighter than that of a stream whose flood-plain enters from the side or that of a torrent. The latter, having little or no flood-plain, is confined to its valley until close to the lake. Thus the delta is fan-shaped, and the middle line of the fan is higher than the remainder, because the coarsest deposits are laid down near the issuing stream. The heads of many lakes, such as Geneva or Buttermere, have a broad, flat, square-ended delta, which is practically a continuation of the confined alluvial plain; whereas the deltas of the side-streams entering these lakes, such as the Dranse, or Comb Beck, Buttermere, are typically fan-shaped.

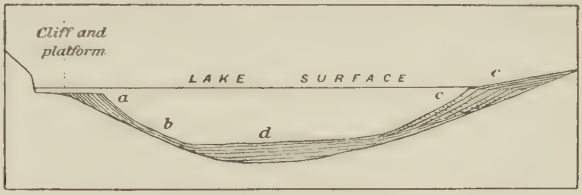


FIG. 177.—DEPOSITS FILLING UP A LAKE.

a, coarse lacustrine deposits; *b*, fine lacustrine deposits; *c*, fluviatile deposits; *d*, fine fluviatile mud.

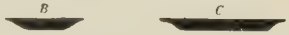


FIG. 178.—CROSS SECTIONS OF BUTTERMERE (B) AND CRUMMOCK WATER (C) AT THEIR NARROWEST PARTS, SHOWING THEIR FLAT FLOORS. (After Mill.)

Tributary streams may push their deltas out from the shore until they eventually cut the lake into two parts, and raise the water-level of the upper part so that it drains across the lowest point of the encroaching delta to the lower sheet of water. In this manner the delta of the Sail Beck has cut off Crummock Water from Buttermere (Figs. 83 and 84).

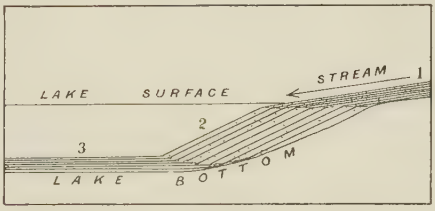


FIG. 179.—DIAGRAM OF A DELTA.

1, alluvium of stream; 2, coarse fluviatile deposits; 3, fine fluviatile mud.

The Sail Beck (Fig. 180) turns abruptly northward to the lower lake without reaching the short river flowing out of Buttermere, which has been pushed over by the delta close against the base of the steep slope on the west. The Rannerdale and Scale Beck deltas fill former bays. It follows, therefore, that what were once the widest parts of Crummock Water will in future be the narrowest.

By the above processes any lake will in course of time become first a marsh, and finally an alluvial flat over which the stream and its tributaries will wander, depositing alluvium with each successive flood until the whole surface is built up as a flat and fertile plain.

A lake is **drained** when the sill over which the water issues is cut through. If the sill is of solid rock, the lake-basin will probably be first filled up, because the issuing waters have been filtered and deprived of tools with which to work. Should, however, the barrier be of incoherent material, like glacial drift, scree, or avalanche, the waters may remove

W. H. Smith

FIG. 180.—THE SAIL BECK ENTERING CRUMMOCK WATER.
(See also Figs. 83 and 84.)

it fairly quickly and drain the lake at an early date. Many lakes have thus been emptied since the glacial period, and the withdrawal of ice naturally drained others.

Evaporation causes many lakes in arid districts to lose their waters: Pyramid Lake and the Great Salt Lake, Utah, are the shrunken remnants of much larger fresh-water lakes, and many others in the same region have totally vanished.

The sites of old lakes may be detected by the presence of alluvial flats or marsh-lands, wider than the normal flood-plain of the river and behind a barrier of some kind, and also by the occurrence of lacustrine deposits (shell-marls, tufa, bog-iron) in the alluvium. Wave-cut shelves, old lake-beaches, and deltas, are also valuable criteria.

Colour of Lakes.—The blue colour of lakes is due to the purity of the water, but is improved by the reflection of the sky. The waters of Geneva are intensely blue in the shade, even upon a dull day. Llyn-dur-Arddu and Glaslyn on Snowdon are of an indigo tint, and Llyn Llydaw is almost as blue. The green and yellow colours of lakes are caused by organic matter dissolved from vegetable substances such as peat, or by patches of vegetable organisms (algæ) and coloured animals. Again, if light is reflected from a sandy bottom through shallow water, the result is a green colour. Minute particles of colourless mud in suspension also give a yellow tint, which combines with the blue to form green.

Salt Lakes are of two kinds: (*a*) Fresh water made salt by evaporation; (*b*) Cut-off parts of the sea.

E. E. L. Dixon.

Fig. 181.—The Great Salt Lake, Utah.

Notice the beach-lines on the hills, marking the former water-levels.

(*a*) In basin-shaped hollows, with interior drainage, salt lakes will be formed if rainfall and evaporation nearly balance each other. In wet seasons the waters become fresher and rise; in a dry season they shrink and become more salt. The Dead Sea, 1,300 feet below the Mediterranean, was once fresh; it now has 24 per cent. of salt by weight.

In Central Asia and the interior of Australia such lakes occur in numbers, but the best example is the Salt Lake of Utah—2,000 square miles—which was once fresh and covered 19,750 square miles, being 1,000 feet deeper than at present, as shown by the well-defined beaches all round the basin.

The temporary lakes of arid districts disappear in the dry season, leaving remarkably flat plains called 'playas' in America. Salt lakes partially dried up are 'salinas' or 'salt-pans.' The outflow of Lake Titicaca (Bolivian Andes) flows through a shallow marshy salina fifty miles long, and is then lost in a broad salina of dazzling white surface.

(*b*) The Caspian level is below the Black Sea, that of Aral is above it, but the waters of the latter are diminishing. The isolation of these seas was partly due to earth movements, partly to diminution in rainfall of the region, for many rivers do not reach the lakes they originally fed, but die away in a waste of sand. The Caspian, near the great river mouths, is fresher than the Black Sea, but in the branch called the Karaboghaz evaporation is excessive, and gypsum is deposited every winter.

In the Triassic rocks (New Red) of Antrim, Cheshire, and Durham, there are deposits of old salt lakes and seas of former geological ages, which furnish us with supplies of salt and gypsum of considerable value. Similar deposits are found elsewhere in rocks of various ages; a mass of rock-salt at Parajd (Transylvania) is over 10,000,000,000 cubic feet in bulk.

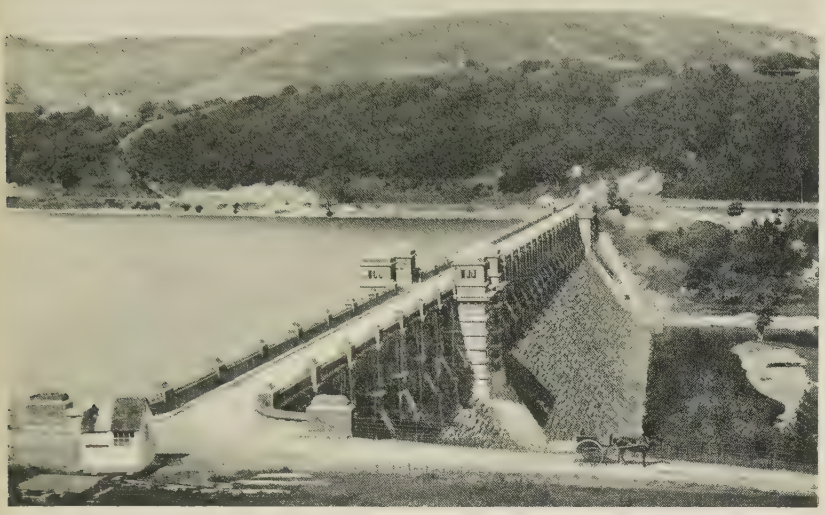
In savage countries the shores of fresh-water lakes often support a teeming population, who cultivate the well-watered valleys and river-deltas, and are engaged in fishing or hunting the animals which frequent the shores. Neolithic man built dwellings, in the lakes of Switzerland, Britain, and other countries, upon piles, out of bowshot from the shore, and similar sites were chosen even in the Bronze and Iron Ages. Lakes and marshes have furnished barriers against aggressive foes; Hereward, in East Anglia, was a match for William the Conqueror until the latter drained the fen.

Of late years lakes have been resorted to for their beauty, especially when lake and mountain are wedded together, and here again the deltas furnish the favour to sites for villages.

In heavily wooded countries rivers and lakes afford the savage an easy path in his light canoe. In more civilized countries, when linked together by navigable waterways—rivers or canals—lakes form highways of great commercial importance. The Caledonian Canal is a case in point; a saving of 250 miles is effected for small boats on a journey from the Forth to Glasgow. The North American Lakes, with canals and the St. Lawrence, afford a marvellous system of inland navigation, giving access for sea-going vessels to Port Arthur, on Lake Superior, 2,260 miles from the Straits of Belle Isle. At no very distant date the Central African Lakes will play an important part in commerce.

Since lake-levels change very little, even in wet seasons, the outlet streams have a relatively constant flow; and floods, like those which inundated Paris in 1910,

are impossible. Lakes also act as filters and purifiers, and are therefore used as reservoirs for great industrial centres: Thirlmere partly supplies Manchester; Loch Katrine, Glasgow; and Ennerdale, Whitehaven. There being no lake available,



Valentine and Sons, Ltd.

Fig. 182.—The Lower End of Lake Vyrnwy (a Barrier Lake).

Lake Vyrnwy, supplying Liverpool, was made by damming up the stream at the lower end of the Vyrnwy Valley. Sheffield and Manchester also draw some of their supplies from artificial lakes.

CHAPTER XIV.

Seas and Coast-Line.

Temperatures.—The surface layers of the ocean are affected by the temperature in different latitudes, being hotter near the equator than near the poles; but since water warms very slowly, the effect of the sun extends only a few hundred feet below the surface. Below this depth there is a mass of cold water, the bottom temperature of every ocean in free communication with the poles being little above, and sometimes actually below, the freezing-point of fresh water (32° F.). In the Atlantic, at the equator, where the surface temperature is 80° F. or more, a temperature

of 40° F. is reached at 300 fathoms, and the same is the case off the Cape of Good Hope, whilst in the North Atlantic warm water descends to greater depths (Fig. 183). Thus, there must be a transference of cold water from the poles to the equator, because the temperature of the great mass of the ocean is much less than is normal to each latitude at the surface. Beneath this temperature of 40° F. there is a similar submarine climate everywhere in the deeper parts of the ocean; the animals living in the deep ocean will therefore be alike, whether near the equator or the poles.

Surface temperatures depend upon latitude, upon ocean drifts and currents, and upon the distribution of land masses. They are very evenly distributed in the open ocean, but become irregular near the continents. Again, because radiation is a slow process, the mid-ocean

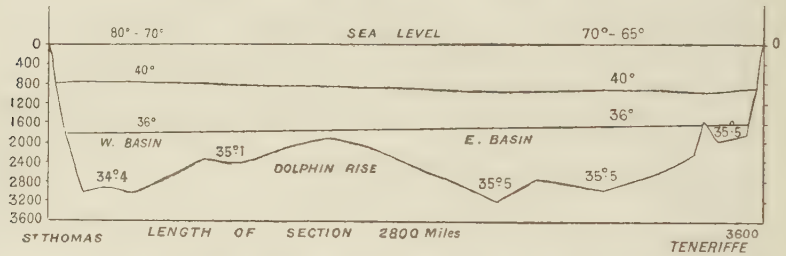


Fig. 183.—Section of North Atlantic from St. Thomas to Teneriffe.

Vertical scale much exaggerated. Depths in fathoms. Temperatures in degrees Fahrenheit ('Encyclopedia Brittannica').

summer and winter temperatures differ only by a few degrees, whereas near the land they vary greatly. The greatest annual change is off the Newfoundland Banks, where there is a cold current at one season, and a warm one at another. Similarly, the daily range in the surface waters of the North Atlantic away from the land is small (about 1·8° F.).

Circulation.—The movement of cold water from the poles to the equator is compensated by a drift of the surface waters in the opposite direction—the combination being known as 'planetary circulation.' The warm waters flow polewards, become cooler and more dense, sink to lower depths, and return again to the equator, where they once more rise to the surface. In some cases this bottom movement of cold water is prevented by elevations in the sea-floor, over which the heavy water cannot creep. Thus, the cold Arctic waters enter the North Atlantic only by the 500 to 600 fathom channel in the submerged ridge between

Scotland and Greenland. Again, the waters of the Mediterranean enter over comparatively shallow straits, which exclude the deep cold Atlantic

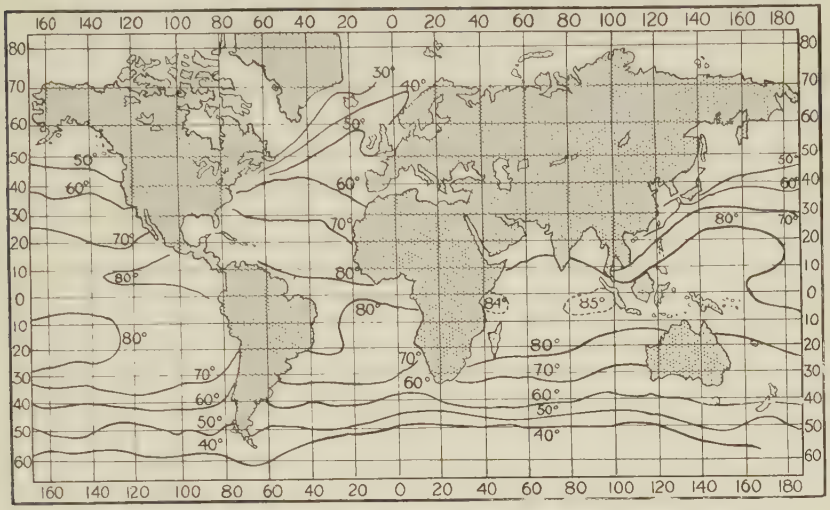


FIG. 184.—ISOTHERMALS OF THE SURFACE OF THE SEA FOR FEBRUARY.

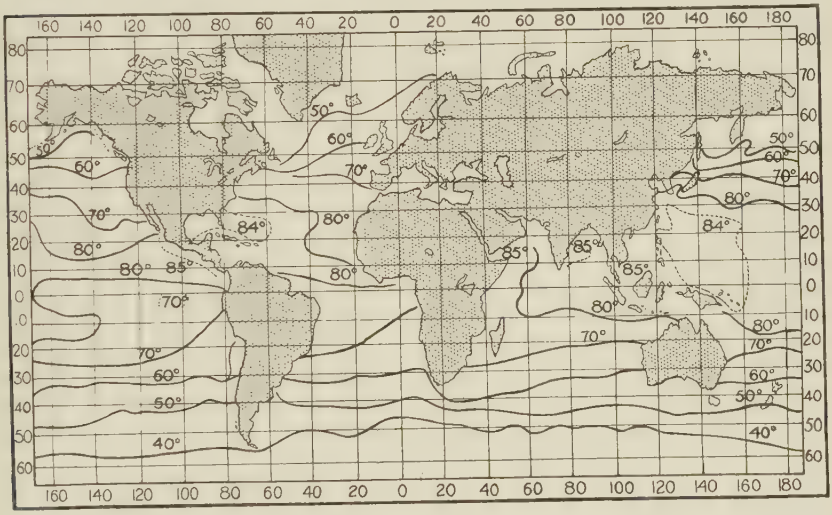


FIG. 185.—ISOTHERMALS OF THE SURFACE OF THE SEA FOR AUGUST.

Temperatures in degrees Fahrenheit.

waters, and allow only the warmer waters to enter. Polar waters are similarly excluded by the Straits of Babelmandeb from the Red Sea, whose surface temperature therefore occasionally rises to 106° F.

Besides this general vertical circulation of the ocean, due mainly to temperature, there is a horizontal circulation of definite ocean currents.

The Equatorial Current, impelled partly by the Trade Winds, moves in a general westerly direction round the globe, but suffers considerable deflections owing to the continents across its path. That portion which crosses the Atlantic from Africa divides, one branch turning south-west, the other north-west—a considerable part of the latter passing into the North Atlantic outside the West Indies. The part which enters the Caribbean Sea, passes through the Straits of Yucatan into the Gulf of Mexico, where some of it circles round, and emerges at the southern end of Florida. Yet another part passes northward through the West Indies; therefore, by the time it has reached the latitude of the Carolinas, the warm drift of the North Atlantic is composed of several parts.

The water emerging from the Gulf of Mexico is known as the *Gulf Stream*, and passes northward with a portion of the Atlantic drift which did not enter the Gulf. At about the latitude of Cape Hatteras the Gulf Stream is turned to the right by the earth's rotation, and, ceasing to be distinguishable a little east of the Newfoundland Bank—quite 1,500 miles from Britain—is merged into the general north-easterly drift of warm water. This drift is largely responsible for the mild winter temperature of Britain, Norway, and the Faroes, and causes the January isotherm of 32° F. to bend to the north (Fig. 10), and actually cross the Arctic Circle.

One branch of the drift returns as a surface current along the coast of Spain and Africa, there joining the Equatorial Drift. The water thus forms a complete whirl in the North Atlantic. Another important current in the North Atlantic is the cold *Labrador Current*, which gives rise to the low winter temperature of New York, which is in a much lower latitude than the south of England. Similar whirls and currents occur in the South Atlantic, South Pacific, and Indian Oceans. In the North Pacific a circulation similar to that of the North Atlantic is established, and from it the Japanese Current, or *Kuro Siwo*, is produced, which washes and warms the western shores of the United States.

The belt of calms between the Trade Winds is mostly north of the equator; therefore the drift of water is greater in the Northern Hemisphere than in the Southern. Continental interference and the deflective action of the earth's rotation are mainly responsible for the paths pursued by the currents, which produce unequal temperatures on opposite sides

of the continents (Fig. 184). In the centre of the whirls the free floating weed, *Sargassum bacciferum*, or gulf weed, accumulates in great masses. One such mass, the Sargasso Sea, covers thousands of square miles in the North Atlantic whirl, and is the home of hosts of marine creatures.

The Tides.—The oscillations of the oceanic waters caused by the sun and moon (p. 6) are known as the 'tides.' In the deep ocean the tidal wave is hardly noticed, its rise and fall being limited to 3 or 4 feet. It moves with great speed—in the Atlantic at quite 500 miles an hour. The wave is merely an *oscillation*, in which the different water particles are raised up and lowered again; and from crest to crest it measures several thousand miles. High tide due to the crest of the tidal wave occurs every 12 hours 26 minutes; low tide is caused by the succeeding trough.

The British Isles stand upon a submerged and gently undulating platform or continental* shelf, nowhere more than about 100 fathoms below sea-level. When the tidal wave, travelling rapidly across the Atlantic from the south-west, comes to this shelf, its speed is reduced to less than 100 miles an hour; the lower parts are retarded and *overridden* by the higher parts, which pile themselves up in the narrow and shallow seas surrounding the Isles.

The tidal wave, striking the coast of Ireland, wraps round the British Isles, penetrating on one side up the English and St. George's Channels, and on the other through the North Channel and Pentland Firth. As a consequence, the water is high simultaneously at Liverpool, at Dover,

* Beyond the 100 fathom line the sea-bed slopes downward with the steepness of a visible hill to a depth of 1,000 fathoms. Very small changes in the sea-level would suffice to join Britain to the Continent, or to flood the low grounds and put a wide sea between Britain and the mainland. In the past both of these conditions have been fulfilled.

Upon the surface of the shelf the most marked feature is the Norway Deep, which follows the outline of Norway from the head of the Skager Rack to the continental edge, attaining a maximum depth of 400 fathoms. Between Denmark and England is the shoal known as the 'Dogger Bank,' whose north-west margin is a submerged escarpment, apparently connected in some way with the Cleveland district of Yorkshire and the north-west of Jutland, because peat and seeds have been dredged from the bank, implying that it has been fairly recently a land surface. The deeper parts of the shelf probably represent old valleys or submerged estuaries of rivers, which traversed such plains as are now represented by the English, Bristol, and St. George's Channels (Fig. 186).

and a little east of Pentland Firth. In the North Sea the northern tide follows the East coast of Britain, and brings high tide to Dover 12 hours after it left Pentland Firth—that is to say, 12 hours later than the same

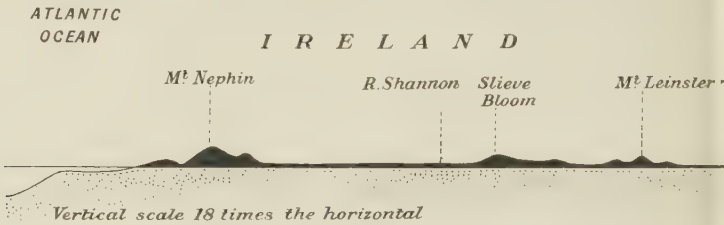


Fig. 186.—Section across the Continental Shelf from Tf

tidal wave travelling up the English Channel. By this time a second tidal wave has travelled up the Channel to Dover, hence at this point two high tides occur simultaneously, and combine to form a very high tide. Again, at a point midway between Holland and England, the northern and southern tides, one falling and the other rising, neutralize each other, and there is no perceptible rise and fall.

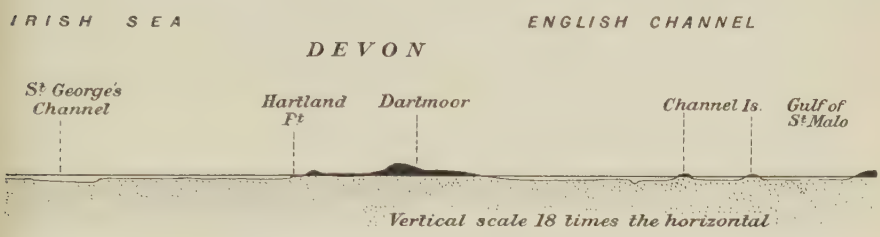
Minor inequalties, such as small islands and straits, cause similar interference of tides. At Southampton there are four tides a day, high water at Spithead being 2 hours later than high water from the Solent.

In shallow seas the rise and fall of the waters is accompanied by tidal races and currents, which are of great advantage to commerce, and play an important part in sculpturing the coast-line. At flood-tide the currents flow with the advancing tidal wave : at ebb-tide they are generally reversed, but through local interference the two currents are not quite the same, nor does the change take place at the time of high water.

Through Pentland Firth the ebb and flow produces an alternating *tidal race*, running with a speed of from six to ten knots an hour, about three times the speed of large rivers. Again, between Guernsey and the Casquets the current sets from every point of the compass during each rise and fall of the tide ; hence the navigation is exceedingly dangerous in foggy weather.

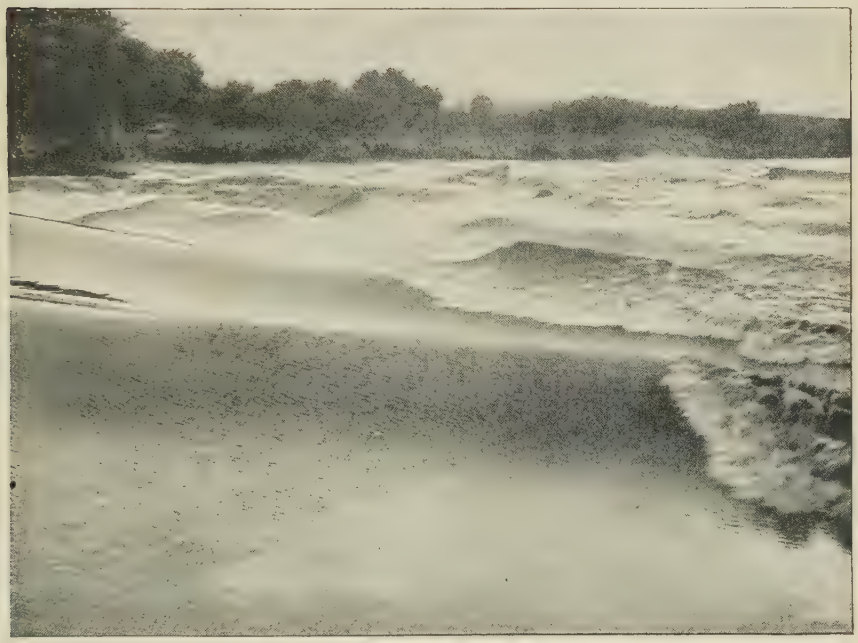
The height of the tide varies from zero up to 60 or 70 feet ; it is greatest where the tidal wave is cooped up within a shallow, steadily narrowing inlet, where the advancing tide may gather itself up into one or more large waves, and rush furiously up between the converging shores. Thus, at Chepstow the water rises 50 feet at spring tide, whilst a wave, known as the *bore*, is propelled up the Severn until its energy is destroyed by the strength of the descending stream.

Similarly, a bore flows up the ri er at Bridgewater and others opening upon the Severn. The Trent bore, locally called the 'Aegir,' is from 4 to 5 feet high near Gainsborough. In the Bay of Fundy the tides reach a height of 70 feet,



Atlantic Coast of Ireland to the Gulf of St. Malo, France.

and on the Tsien-Tang Kiang, 70 miles from Shanghai, the bore rushes up the estuary as a huge breaker 20 feet or more in height, with a speed of sometimes eight knots an hour.



F. M. Burton.

Fig. 187.—The Aegir, or Trent Bore, at Gainsborough.

If the tide rises higher upon one side of a strait than another, a very powerful *race* rushes through the strait. At Hell Gate, near New York, the race is due to the higher tide in Long Island Sound than in New York Harbour.

The Sea Coasts.

When we read of the damaging effects of the waves upon the sea coasts, or see them for ourselves, we are apt to attach undue importance to the sea as a destructive agent. The losses on our shores are really much less than the losses on the surface of our islands caused by the ordinary weathering agents. Sir Archibald Geikie has stated that if the continent of Europe is eaten away by the sea at the rate of 100 feet a century (a rate above the average), it will require over 5,000,000 years for the sea to consume a strip 100 miles wide. But in the same time the whole of Europe would be almost worn to sea-level by the atmospheric agents.

Waves.—Consider a simple uplift of the sea-bed, giving rise to a tract of land which emerges at a low angle from the water. So long as the sea remains still and calm, it will have very little effect upon the shore-line, which would consist of simple flowing lines and curves corresponding with the inequalities of the uplifted surface. The sea, however, is disturbed by wind, waves, ocean currents, and tides; each of which helps to modify the simple shore-line—the waves chiefly as *eroding agents*, the currents and tides as *transporting agents*.

Waves in the open and deep ocean are, like the tidal waves, simple *oscillatory* movements. The wave moves forward, but the particles of water merely oscillate about a position of rest. A boat in the open sea is not carried forward on a wave; it merely rises and falls like the water particles. These waves, or undulations, produced by the wind blowing over the ocean surface, travel onwards in ever-diminishing size beyond the district in which they are born. They are then known as 'ground swell.' When a wave nears the shore, it passes into shallow water, its trough is retarded by friction with the bottom, and the crest moves on over it, so that there is now an actual *forward movement* of the water; the crest tosses into foam, and the wave thunders on the beach as a 'breaker.'

Breakers play their part in destroying and sculpturing the land in several ways:

(*a*) The average force of the Atlantic rollers in winter is nearly 1 ton per square foot. In the Shetlands the waves have actually quarried blocks 13½ tons in weight from their bed, and at the Peterhead breakwater blocks of 40 tons have been displaced. The force of the stroke delivered naturally varies with the inclination of

the object upon which it falls. A wave on a flat shore will do very little damage as compared with one falling upon a sharply inclined cliff.

(*b*) When the waves hurl themselves against a sea-wall or cliff, they drive air into cavities, and hold it for a time under tremendous pressure, which often has the effect of enlarging the crack and loosening the fabric. The air, when released, rushes out with great force.

(*c*) The water itself, driven into hollows, exerts in all directions an hydraulic pressure equal to that force with which the wave falls upon the shore.

(*d*) *Breakers act most effectively by picking up rocks, shingle, and sand, which they hurl violently forwards.* The greatest height to which wind waves rise in the open sea is about 50 feet, but sand and stones may be carried over twice this height, especially if aided by an on-shore wind. The windows of the Dunnet Head Lighthouse, 300 feet above the sea, have frequently been broken by shingle swept up from the beach below. On a pebble beach, like that near Sheringham, the roar can be heard for miles; the stones are hurled forward against the cliff, and then dragged back by the undertow, until they are reduced to well-rounded shingle.

Judges, Ltd., Hastings.

FIG. 188.—A 'BREAKER,' HASTINGS.

Tides help the waves in their destructive work by moving the water up and down against the rocks so that the breakers have a large surface to work over.

Cliffs.—In the above manner the waves eat their way into the land, and cut a gently sloping platform backed by a cliff, whose upper parts, beyond the reach of the waves, would overhang were it not for gravity and atmospheric weathering. The wave-cut *platform* lies mainly between the lower limits of wave action and high-tide level.

H.M. Geographical Survey.

FIG. 189.—GRANITE BOULDERS ON SHORE, ST. AGNES, CORNWALL.

The Chalk Downs east of Newhaven face the sea with a vertical cliff, from which so much land has been cut away that the truncated ends of many valleys are seen hanging above the beach (Fig. 192).

The rate at which the sea attacks the coast depends upon the nature and structure of the rock and the removal of the eroded material, for the sea cannot easily batter a cliff which has its base smothered in débris. In general the sea wears away soft rock faster than hard rock. In *hard*

M. E. Jolley.

FIG. 190.—THE NORTH LANDING, FLAMBOROUGH.

Showing cliff and wave-cut platform exposed at low tide.

rocks structural planes influence both the progress of the sea and the shape of the cliff. The weak spots are quickly discovered and enlarged, so that well-jointed and bedded rock is quickly quarried away. Rocks with horizontal bedding and vertical joints tend to form precipitous cliffs; if the dip is away from the sea, the cliff slopes back in steps; if towards the sea, the cliff may overhang, but an overhanging cliff is a rarity.

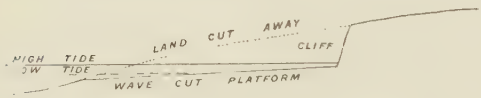


FIG. 191.—DIAGRAM SHOWING FORMATION OF CLIFF AND PLATFORM.

Caves are formed by the sea enlarging joints or stratification planes, and quarrying away blocks of rock. If the mouth of the cave is between high and low water marks, the breakers entering the cave will compress air into the joints in the roof so as to detach blocks, and the roof some-

times collapses, letting in light from above, and giving rise to a 'blow-hole' through which the waves are violently forced with a puffing noise.

FIG. 192.—THE SEVEN SISTERS NEAR BIRLING GAP, SUSSEX.

Again, *chimneys*, running up the face of the cliff, are determined by joints; the portion between two chimneys is left projecting. Promontories may be actually drilled through, so that a *stack* or *natural arch* is formed (Fig. 194).

Photochrom Co., Ltd.

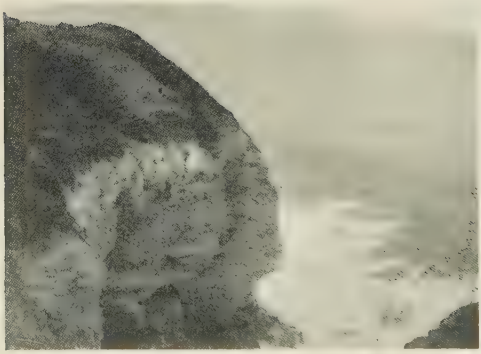
FIG. 193.—THE NEEDLES, ISLE OF WIGHT.

Stacks of chalk dipping at a high angle.

The extremity of the limestone promontory south of Bantry Bay is riddled with caves in which the sea water may be seen by looking down holes in the fields. Fingal's Cave, Staffa (Frontispiece) is a good example of the sea working along columnar joints in basalt. In the Orkneys an isolated stack of Old Red Sandstone (*The Old Man of Hoy*) rises 600 feet from the sea near cliffs almost 1,000 feet high.

Photochrom Co., Ltd

FIG. 194.—THE BATHING COVE, DAWLISH, DEVON.
Stacks and arches in New Red Sandstone.



M. E. Jolley.

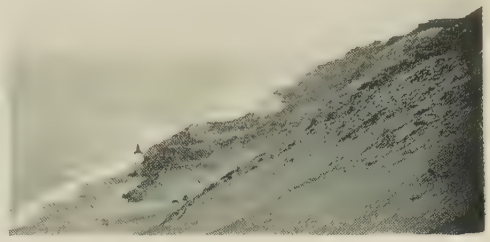
FIG. 195.—LITTLE THORNWICK, FLAMBOROUGH HEAD.

Showing precipitous chalk cliffs undercut by waves and pierced by caves; also the unequal atmospheric weathering of the hard chalk and the soft boulder clay resting upon it.

In *soft rocks* the sea can work more easily and evenly, since structural planes are rarer, thus the outline of the coast is smoother.

The *top of a cliff* is usually farther inland than the base—an effect caused by atmospheric weathering. If a sea-wall is built at the base, the remainder of the cliff will soon be denuded back until it slopes at the angle of rest. On an exposed headland the sea keeps pace with atmospheric weathering of the cliff, but in sheltered bays, where the sea has little attacking power, weathering is the chief factor, hence bold cliffs

are uncommon in the recesses of bays.* Even cliffs of clay in exposed positions may be relatively steep; the boulder clays of the Holderness and Cromer coasts are cases in point (Fig. 196). Tidal scour causes the base to recede at a great pace, although atmospheric agents and waters percolating from inland are continually bringing the top tumbling down to the beach.



A. T. Metcalfe.

FIG. 196.—A LAND-SLIP AT CROMER.

The cliffs are here formed of contorted glacial sands, gravels, and clays, resting on boulder clay.

Just as the harder rocks of a land surface form escarpments and hills, and the soft ones valleys and plains, so the harder rocks of the coastline project seawards as headlands, whilst the softer form inlets and bays. The chalk and limestone of Purbeck form the bold downs running seawards as headlands, fretted into caves and stacks at their extremities (Fig. 198); the softer clays and sands form the low ground and the bays of Totland, Swanage, and Worbarrow.

Rock waste gathers on the wave-cut platform to form beach material. The forward movement of the waves carries pebbles and sand on shore, while undertow tends to drag them down again, and since this is weaker than the forward movement, the larger stones become heaped up on the higher part of the beach. Large stones are moved about fairly easily, because they offer considerable purchase to the water, and can roll over the smaller stones. Sand lies mostly between tide-marks.

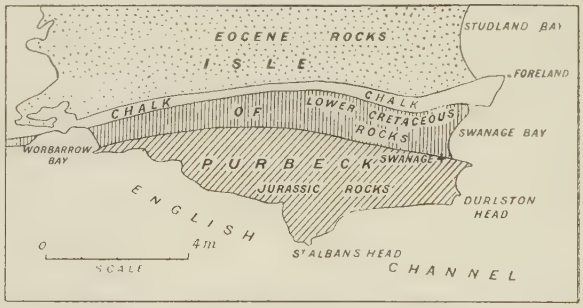


FIG. 197.—GEOLOGICAL SKETCH-MAP OF THE ISLE OF PURBECK. (See Fig. 198.)

* Fjords (steepened by glaciation) and estuaries with strong tidal scour are exceptions.

Waves, tides, and currents (1) move beach material backwards and forwards about the same spot, (2) carry it well out to sea, or (3) move it along shore and deposit it elsewhere.

If the wind blows obliquely to the shore the breakers come in slantwise, throwing up the pebbles in a slanting direction. They roll down the beach, however, in a straight line, and are again thrown up slantwise,

W. Pouncy, Dorchester.

FIG. 198.—DURLSTON AND SWANAGE BAYS, SHOWING THE HARD ROCKS PROJECTING AS HEADLANDS.

Notice stacks of chalk at the end of the Foreland. (See Fig. 197.)

so that their progression alongshore is zigzag (Fig. 199). Prevalent winds cause currents to flow along shore, carrying sand which is deposited and heaped up as dunes elsewhere. The rising tide also forms a fairly strong current, which sets along the coast.

In this and in other ways beach material is drifted along, but never seems to travel very far; the coarser portions seem incapable of passing prominent headlands to any great extent. Currents drop their loads in the slack waters of bays, where much more would be deposited were it not for the strong undertow off the beach. In some cases the drift is carried past the indentation, and deposited as a *shingle-spit*, *foreland*, or *bar*, which may be carried from the mainland to an island, and *vice versa*, forming a peninsula, or may eventually cut off the bay, and convert it into a lagoon, which in time becomes a marsh capable of being reclaimed (Fig. 200). Many British harbours and estuaries also are enclosed by sand-bars, which are in many cases so formidable, when the tidal scour is weak, that the

FIG. 199.—MOVEMENT OF BEACH MATERIAL ALONG SHORE.

courses of the rivers are continually altering—*e.g.*, the Alde. In the shallow waters of protected bays salt-marsh vegetation (grasses) at about normal high-tide level, by its growth and death, and as an aid to entrapping sediment, helps to fill up the estuaries. In the warm surf-beaten tropical seas mangroves, standing upon a network of roots in salt water, hold up sediment, which is deposited behind them in shallow water. When they die, their remains also accumulate in the shallows, and then the land area is increased.

Spurn Point is a low, flat spit of sand and shingle built across the Humber by the tidal current coming down the North Sea. The river has breached it more than once. Dungeness is a foreland said to have extended a mile seawards within living memory. It consists of about twenty ridges ('fulls') of gravel at its widest part, and has cut off a large embayment, first converted into a marsh (Romney Marsh) below high tide level, but now reclaimed and drained, the sea being kept out chiefly by a Roman sea-wall between New Romney and Hythe. The Chesil Beach links Portland with the mainland. Some years ago masses of iron-stone were removed from the beach under Hengistbury Head, Hants. The beach material previously held up by these masses promptly drifted round the headland, and made the old sand-bar across the Avon quite a mile longer than before.

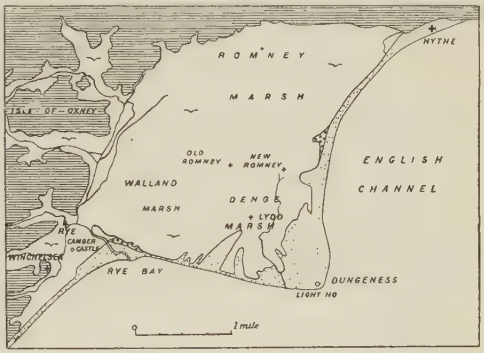


FIG. 200.—DUNGENESS AND ROMNEY MARSH.

Light stipple, sand and pebbles. Heavy stipple, sand-dunes. ~~ alluvium. (See Figs. 201 and 202.)

Thus, the tendency is for inequalities of the coast-line to be obliterated, and the outline finally simplified—partly by erosion, partly by deposition. A series of concave bays is separated by prominent headlands (Fig. 197), the positions of which are in the first place due to the resistance of the rocks. When the smaller bays have reached a certain depth, the waters become slack, and deposit takes place until the headlands are cut back. Equilibrium is therefore established, the depth of the bay bearing a constant ratio to the prominence of the headlands upon either side of it.

Beach material is the coast's natural protection; at ordinary times the waves expend their energy upon it, and leave the cliff untouched. The supply is limited, and the quantity as a rule constant; if, therefore, any is removed, the sea immediately attacks the cliff until it has made good

the loss. Deposit, as mentioned above, may at times becomes so great that the sea is held back. Sand-reefs are built offshore by the beating waves, and sand-dunes from 50 to 100 feet high often form an additional protection to the coast (Fig. 202), and may hold behind them fresh-water lagoons.

In addition to the beach material, the seaweeds of olive-brown and olive-green colours, which sometimes clothe the shore between and below tide-marks—*e.g.*, at Hunstanton—protect the coast by acting as a cushion for the waves to break upon.

L. Edna Walter.

FIG. 201.—DUNGENESS SEEN FROM THE LIGHTHOUSE, SHOWING 'FULLS' AND BEGINNINGS OF COARSE VEGETATION. (See Fig. 200.)

The ultimate fate of beach material is to form new deposits in deeper water out of reach of the waves.

Uplift *simplifies* the outline of the coast, for a sheet of recent marine deposits, upon which the sea works evenly, is exposed as a coastal plain, and the old wave-cut platform and beach is lifted above the reach of the waters.

On the Scotch coast several raised beaches may be counted at different levels 20, 50, and 100 feet (Fig. 203). The broad plain of the Tay, near Stirling, is a spread of raised marine alluvium, and so also is the fertile Carse of Gowrie (Fig. 140).

Conversely, **depression** tends to make the outline of the coast more *complex*, because valleys and plains are flooded by the sea. To this cause

L. Edna Walter.

Fig. 202.—Sand Dunes near Romney, Dungeness.

Romney Marsh (Fig. 200) is behind the dunes on the right.

we attribute the deep inlets of the west coasts of Ireland and Scotland, and the estuaries of the British Isles. They are drowned valleys, as shown by their branching arms, although those in the north are true fjords, having been partly scoured by glaciers.

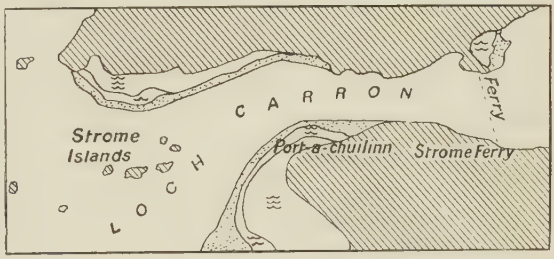


Fig. 203.—Raised Beaches, Port-a-Chuilinn, Loch Carron, Scotland. (See Fig. 204.)

~ raised beach ; ≈ 30 to 50 foot beach ; ≋ 100 foot beach.

If the land were to remain at its present level, the sea would finally reduce it to a *plain of marine denudation*, whose surface would be just below the limits of wave action —*i.e.*, below 100 feet. As a rule, uplift or submergence takes place before a large plain can be

produced, yet there is a wide wave-cut shelf off the West of Ireland, where the coast is exposed to the open Atlantic.

Plains of marine denudation of past geological ages are frequently found with relics of marine deposits upon them; in Pembrokeshire, as before mentioned, there is a so-called marine platform cutting horizontally across rocks of various degrees of hardness, dipping at various angles (Fig. 137).

Deltas.—Marine deltas are very similar to lake deltas, except that their outer faces are usually less steep because of the moving waters. Large river deltas consist of fine-textured waste very similar to that of the flood-plain, of which the upper surface of the delta is, in fact, the continuation Delta formation is ideal when a large river enters a shallow,

H.M. Geological Survey.

Fig. 204.—Raised Beaches (30-foot and 100-foot beach), Port-a-Chuilinn, Loch Carron, Scotland. (See Fig. 203.)

almost tideless, sea. Strong tides and currents round off, and modify the extremity of a delta, and sometimes entirely prevent its formation. The finger-like prolongations of large deltas, like that of the Mississippi, are due to the river splitting up on the convex surface into several branches, called *distributaries*, each one of which builds out parallel embankments rising above the surface for some distance beyond the general margin of the delta. The distributaries of the Ganges and Brahmaputra form a great ramifying network covered with reeds, grass, and shrubs. On a rocky coast deltas of mountain torrents are of coarse stony texture, resembling the alluvial fans built across valley floors.

On the British coast-line deltas are uncommon, because most of the big rivers enter estuaries where the tidal scour is considerable. Some are found, however, at the heads of deep inlets and land-locked bays, but none are sufficiently old to project from the coast-line. In Norfolk the estuaries behind the sand-bars are partly silted up by delta growth at their heads, the tracts of water remaining as Broads (p. 137). Christchurch Harbour, Hants, is silting up behind its sand-bar much in the same way.

Islands.—Close to continents islands are often composed of rocks of the same kind as those of the mainland, having been isolated either by downward movement, which allowed the sea to surround a tract of high ground, or by the sea breaching the neck of a peninsula; they are therefore called **continental islands.**

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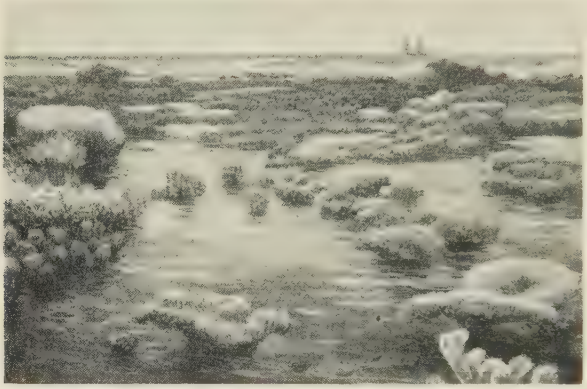
FIG. 205.—FOWEY AND ESTUARY, CORNWALL.

Looking south.

The British Isles stand upon the continental shelf, separated from the rest of Europe by a combination of marine erosion and submergence; and, similarly, smaller islands are fragments of the British Isles. The Isle of Man is structurally a part of the English Lake District, and the Chalk of Purbeck was once continuous with that of the Isle of Wight. Most of the islands west of Scotland are due to submergence of parts of the continental shelf. Other islands, such as Ailsa Craig, in the Firth of Clyde, and the Bass Rock (Fig. 65), Haddingtonshire, are resistant rocks, not easily destroyed by the sea.

Oceanic islands are volcanic or coralline. *Volcanic islands* often rise steeply from the deep ocean, and often occur in chains like that between the Santa Crux Islands and the south of the North Hebrides, each island being a distinct volcano.

Coral islands are formed by the continuous growth of corals. Each individual, or polyp, builds a skeleton of carbonate of lime, and these combine to form masses of coral of wondrous beauty, which, when the animals die, become compacted into rock. The polyps cannot live below depths of between 30 and 40 fathoms ;* they also die if exposed to sun and air, and therefore build up to low-tide limits. They require warm water (68° F. at least) and abundant food, which is best supplied by the equatorial currents ; hence coral islands are prevalent on the East of Africa, Central America, and Australia.



Percy F. S. Spence.

FIG. 206.—THE GREAT BARRIER REEF, EAST AUSTRALIA.

When coral reefs begin to grow, they advance outwards, the living parts being outside, the dead and dying* inside, whilst the surf breaks off masses of coral and tosses them upon the reef together with calcareous sand and coral mud, which cements the whole mass into solid rock. Fissures in the reef are also filled with foraminifera, urchins, and calcareous algæ. Thus low islets are formed, upon which palms and other plants, whose seeds may be carried by birds, or drifted from land, take root and flourish.

A *fringing reef* is usually built on the wave-cut platform round the shore of an island. Inside there is a lagoon formed by removal of the dead coral by boring animals or solution. As the reef grows outwards, it reaches the edge of the shelf, and then continues upon the talus of broken coral fragments which fall into water too deep for coral growth ; the reef then becomes a *barrier reef* separated from the land by a wide lagoon (Fig. 208).

* See note on Coral Islands (Appendix B).

The Great Barrier Reef, 250 miles long, and 10 to 90 miles broad, is built on the edge of the Australian continental shelf. The gaps in this reef are frequently stated to have been due to the fresh waters of rivers preventing coral growth when the reef was a fringing reef and the land at a higher level. This is not the case, however, for the rivers still exist, and yet there are no corresponding gaps in the reefs near the shore, and in some cases there are gaps in the outer reef, with no rivers entering the sea in their vicinity.

Atolls are ring-shaped coral islets,* with a lagoon in the centre having several passages to the outside. Their origin seems to be varied. A mound on the sea-floor might be raised to about the 35-fathom line, either by rise of the sea-bed or by accumulation of the hard parts of marine animals. Corals would then build a reef whose centre, by decay of the corals, would be quickly occupied by a lagoon, leaving the outer rim as an atoll. Ocean currents may cut down land, and form submarine banks upon which reef-builders establish themselves. If an island is

Fig. 207.—An Atoll.

subsiding, the fringing reef would give place to a barrier reef, and, finally, as the centre of the island sank out of sight, to an atoll ; but this method of formation—suggested by Darwin—is not so common as was once supposed ; in fact, very rapid depression would kill off the corals in deep water (Fig. 211).

Primitive man was at first scared and repelled by the sea ; he was on the defence, especially on the flat coasts. Next he erected dykes to secure low-lying ground, like that of the Fens or the North of Germany and Denmark. Next he boldly trusted himself to the waters in his 'dug-out' as a fisherman, or through fear of his foes, or because he was attracted by distant shores. Thus colonization commenced. The Vikings (People of the Bays) were the first Europeans to venture, and discovered Greenland over 1,000 years ago.

An irregular coast-line gives to its inhabitants a nautical impulse and skill in handling craft ; its outlying islands tempt the explorer ; its bays afford good and safe harbourage ; its people become expert fishermen and sailors. Seamanship encourages the spirit of adventure and a wide intellectual horizon, enlarged by contact

* See note on Coral Islands (Appendix B.).

with foreigners. Closeness to the sea promotes science and technical skill in building ships and engines. Knowledge of every part of the ocean is followed by trade with every part, and the ocean provides the cheapest path to carry the goods. Consequently, those countries like Britain, whose seaports are far inland in bays, fjords, and estuaries, can conduct their trade most economically. The rise in seamanship in North-West Europe was largely due to the discovery of America. Instead

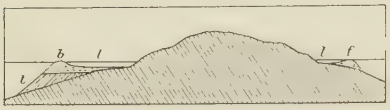


FIG. 208.—SECTION OF AN ISLAND WITH WAVE-CUT SHELF AND REEFS.

f, fringing reef; *b*, barrier reef; *l*, *l*, lagoons; *t*, talus of coral. If of limestone the island may be destroyed by solution and an atoll formed.

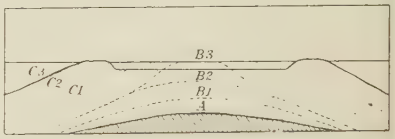


FIG. 209.—FORMATION OF AN ATOLL UPON A MOUND ON THE SEA-FLOOR. (After Gardiner.)

A, mound on sea-floor; B1-3, growth of floor to form surface reef; C1-3, extension outwards and formation of atoll.

FIG. 210.—FORMATION OF AN ATOLL UPON A SUBMARINE BANK DUE TO WAVE ACTION. (After Gardiner.)

A, contour of original island; B, same cut down to form plateau; C, the atoll reef.

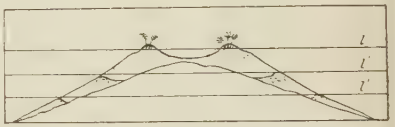


FIG. 211. — DIAGRAM ILLUSTRATING THE SUBSIDENCE THEORY OF CORAL REEFS. (After Bringham.)

l'', *l'*, and *l*, represent sea-level, which, for convenience, is shown as rising.

of being the end of the known world, England became the centre, and now owns over two-fifths of the maritime carrying trade of the world. The sea is her protection against hostile foes, but an easy means of access to friends, and a large part of her food is taken off the continental shelf, one of the best fishing-grounds in the world. Every breath of wind from the sea penetrates far inland, and is laden with moisture, which fills the rivers and renders the pastures verdant.

CHAPTER XV.

Physical History.

IN previous sections we have studied in detail various natural processes and the effects to which they give rise. It will now perhaps be well to take a special area, and, by reviewing its life-history, notice how its broad physical features have been impressed upon its surface according to the mould in which it was cast and the vicissitudes it has undergone.

For this purpose we need go no farther than the British Isles, within whose compass there are probably more different types of rock than in any other similar-sized area in the world. These same rocks

FIG. 212.—SECTION ACROSS ENGLAND AND WALES. (After Ramsay.)

account for the infinite diversity of surface, of soils, of inhabitants and their pursuits. Mountain and upland, valley and plain, are determined by the distribution and arrangement of the rocks and their varied composition and structure—sculptured by Nature's hand.

The numerous rock types are due to the situation of the British Isles at the extremity of a great continent, where alterations in the level of land and sea have been many and frequent. Part of what is now the British Isles was nearly always above water, but it rarely happened that it was the same part.

A geological section from Anglesea to Dover shows that the oldest and toughest rocks occur in the mountainous districts of Wales, whilst the younger and softer rocks dip off them to the south-east, and form the lower hills and plains of England (Fig. 212).

FIG. 213.—OLD AND NEW ROCKS OF THE BRITISH ISLES. (See also Fig. 212.)

Black, Pre-Permian; white, Post-Carboniferous.

Borings through these younger rocks near London and Dover have proved that rocks similar to those of the Welsh Borders lie beneath St. Paul's Cathedral, within $\frac{1}{4}$ mile of the surface. In fact, there is an irregular subterranean platform of older rocks, upon which the lower members of the younger series rest unconformably, whilst the higher

members overlap them and cover up the platform in regular succession. At one time the younger rocks also concealed many of the old rocks in

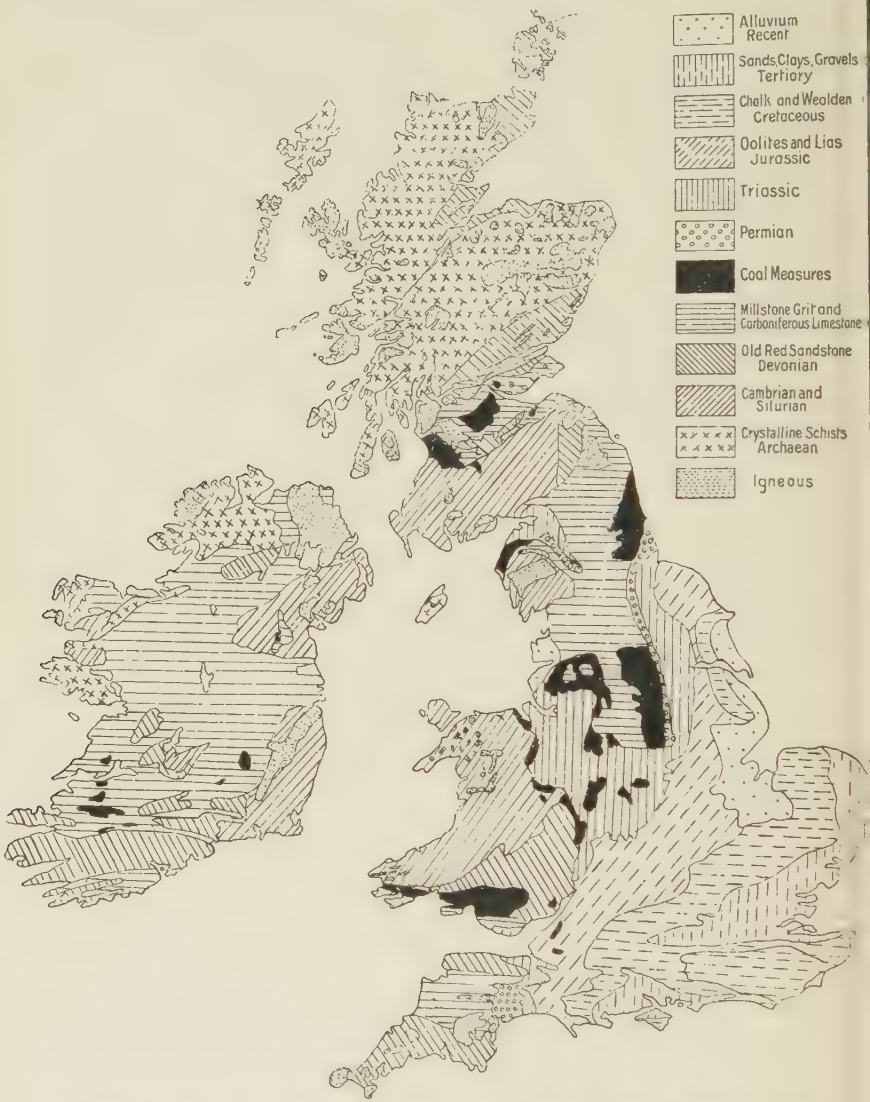


FIG. 214. —GEOLOGICAL MAP OF THE BRITISH ISLES. (After Bartholomew.)
Lower Silurian = Ordovician in the classification on p. 173 ; Archæan = Pre-Cambrian.

the west, but have been stripped off by denudation. Had England, during its later history, been tilted to the west by earth movements,

instead of to the east, the old rocks beneath London would have been raised far above sea-level and the conditions reversed; the south-east of Britain would be rocky and mountainous; the west might have been covered by soft rocks, forming lowlands and plains.

The rocks of the British Isles are geologically classed as follows—the oldest first, the youngest last:

First Continental Period ..	Archæan or Pre-Cambrian, *accompanied and followed by great earth movements.*	
First Marine Period	Cambrian Ordovician Silurian, *followed by great earth movements*	Primary Rocks.
Second Continental Period ..	Devonian, or Old Red	
Second Marine Period	Carboniferous, *followed by great earth movements*	
Third Continental Period ..	Permian Triassic, or New Red	Secondary Rocks.
Third Marine Period	Jurassic Cretaceous, *followed by great earth movements*	
	Early Tertiary, *accompanied by great earth movements*	Tertiary Rocks.
Fourth Continental Period ..	Late Tertiary Glacial Post-glacial and Recent	Quaternary Rocks.

The diagram (Fig. 215) shows the thickness of each division in England, the total being so great that the lower members would be inaccessible if they were not brought to the surface by earth movements. In the Pre-Cambrian rocks there are few or no signs of organic life. The remainder, or fossil-bearing rocks, represent an enormous extent of time, best appreciated when we remember that Palæolithic man only reached our shores from Europe at the close of the Glacial Period, which is quite recent when compared even with the early Tertiary rocks. The formation of the fossiliferous rocks must have taken millions of years, yet the time required for the Pre-Cambrian rocks was probably greater.

The structure of the British Isles depends very largely upon the four periods of earth movement tabulated above. Movements of less

importance, which took place at other times—for the earth is hardly ever at rest—call for no special remark.

Pre-Cambrian.—The whole of the Outer Hebrides and parts of the North-West Highlands consist of Pre-Cambrian rocks, of which there are two well-marked series.

FIG. 215.—RELATIVE THICKNESSES OF SYSTEMS. (After Jukes-Browne.)

Scale, 14,000 feet to an inch.

These are a lower set of rocks, largely of plutonic origin, much disturbed, crumpled, and broken by earth movements, and formed probably when the earth's crust was thin; and a thick upper series of red (Torridon) sandstones and conglomerates formed under continental desert conditions, resting in nearly horizontal layers (Fig. 154) upon the denuded edges of the lower series.

The region comprising the Central Highlands and all Inverness east of the Great Glen, together with a part of the Northern Highlands, is made up largely of metamorphic, pierced by intrusive, rocks. They now form a great dissected upland, in which the highest summits attain the level of the old plateau (Fig. 138). Both structurally and physically the mountains of the North of Ireland are a continuation of the Scottish Highlands. Pre-Cambrian rocks appear at the surface at several points in England and Wales, but form striking physical features in only a few cases, notably in the Longmynd, Wrekin, Malvern, and Charnwood Forest districts.

Cambrian, Ordovician, and Silurian.—These rocks were chiefly formed in water. In Cambrian times the land lay to the west of Wales, partly over the site of Ireland and the Atlantic; the sea lay to the east, stretching as far as Russia. In Mid-Ordovician times there was a period of tremendous volcanic activity, the eruptions being probably from submarine volcanoes or volcanic islands, chiefly on the sites of what are now North Wales, the Lake District, the coast of Ayr, Wicklow and Wexford; and the resulting rocks account in no small degree for the delightful scenery of these districts. During Silurian times (Wenlock limestone) corals built reefs of great thickness in the warm waters, which in late Silurian times became shallower as the coast-line crept southward and eastward.

The period was closed by powerful movements, the greater part of the British region being subjected to pressure, and elevated to form part of a continent extending west and north. The pressures ridged up the rocks to form mountain districts trending west-south-west and east-north-east, and impressed upon the softer sediments a slaty cleavage. The Southern Uplands of Scotland—continued into Ireland—the Lake District, the Welsh Mountain mass, and the Highlands (Fig. 214 and 215) were blocked out at this time; they are now only the denuded stumps of great mountain-ranges.

Old Red Sandstone.—In the hollows between the ranges deep gulfs received the (sometimes desert) deposits of the Old Red Sandstone. The sea proper lay south of the present Bristol Channel, and collected the marine sediments of Devon and Cornwall. The larger Old Red Sandstone basins have been named by Sir A. Geikie 'the Welsh Lake,' 'Lake Caledonia' (Lowland Plain, Scotland), and 'Lake Orcadie.' From Stonehaven to the Tay the Old Red forms a series of fine cliffs, some being 600 feet high. Volcanic activity also was rife. The structurally weak

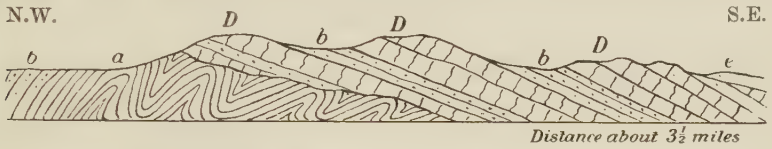


FIG. 216.—DIAGRAMMATIC SECTION ACROSS THE PENTLAND HILLS. (After Jukes-Browne.)

a, Silurian; *b*, Lower Old Red; D, lavas; *e*, Upper Old Red.

flanks of Lake Caledonia (p. 54), 20 miles apart, were lined by a chain of volcanoes; the features of the Ochil and Pentland Hills are entirely due to immense masses of volcanic rock, the lavas forming scarp behind scarp, some hills being actual volcanic necks.

Carboniferous.—Part of the land sank once more, and the sea covered the greater part of the British Isles, extending southward over the North of France. Land lay chiefly through the Highlands, Norway and Sweden, and the Carboniferous Mountain Limestone was accumulated in the land-locked sea. An upward movement then set in, the rivers bringing down sediment until broad tracts of the sea were converted into marshy flats and lagoons, suitable for the growth of the Calamites, Lepidodendra, Ferns, and Conifers, so abundant in the Coal Measures.

There was volcanic activity of the *puy* type throughout this and the succeeding period, and many intrusive masses were thrust into the sedimentary rocks. Dartmoor is a granite of Carboniferous age.

Earth movements at the close of the period (continued in modified form into Permian and Triassic times) caused uplift of a large district, so that the climate became desert and continental. Two systems of mountain-building occurred, producing elevations running respectively north-south and east-west. The first, or *Pennine* system, consisted in direct uplift and fracture, with little folding (see Basin Range Structure), and to it we ascribe the uplift of the Pennines and corresponding trough of the Eden Valley. The synclinal trough of the Vale of Clwyd also was let down by faulting, and the north and south line of the Malvern Hills established. By movements of the second, or *Mendip*, system, with folding and sometimes reversed faulting, we account for the uplift crossing the Pennines between Lancashire and Yorkshire—so as to separate (after denudation of the ridges) the coal basins of Cumberland, Durham, Yorkshire and Lancashire—and also for the Mendip folds, the lie of the South Welsh coal basin, and the strike of the rocks in South Pembrokeshire, Devon, Cornwall, and the South-West of Ireland (Fig. 214). Ireland as a whole was broadly elevated, and its coal measures heavily denuded from the Central Plain, the débris helping to cover up and preserve those of England.

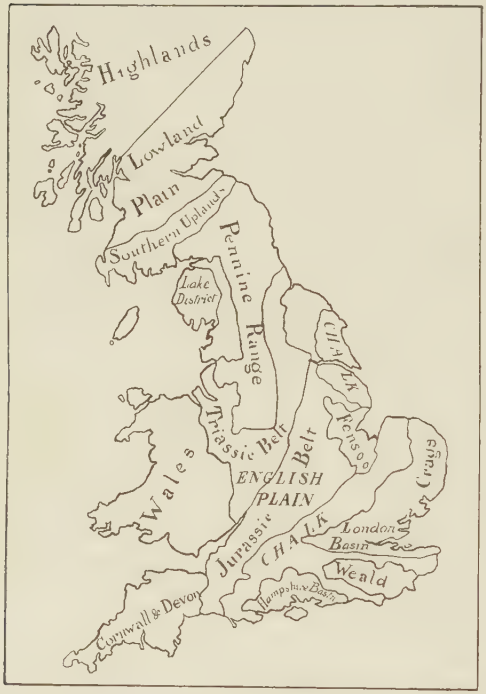


Fig. 217.—The Natural Divisions of Great Britain. (See Fig. 214.)

Permian and Triassic. — These rocks were mainly formed in land-locked waters, or shallow inland seas and salt lakes, covering the low ground and wrapping round the bases of the uplands, which still continued to be slowly uplifted until the close of Triassic times, when a depression set in; the climate was ameliorated, and the sea once more invaded the south and centre of England, and extended north into two great gulfs on each side of Scotland.

Jurassic and Cretaceous.—In these waters were formed, amongst others, the Oolitic limestones (Jurassic) and the Chalk (Cretaceous)—deposits which form two of the best developed escarpments of Central England.

At the close of the Cretaceous the British area once more became part of a continent stretching west and south of its present limits. The upheaval was most rapid in the north-west, so that Ireland and Scotland were raised to a high level and united by a broad plateau extending to the Faroes and Iceland. In the south, anticlinal uplifts (east and west) were formed during the deposition of the succeeding sediments.

Early Tertiary.—The chalk was denuded from the ridges, and the waste, washed from the west, accumulated in the London and Hampshire basins, as marine, estuarine, and fresh-water sediments, at a time when the sea was warm, and a tropical flora and fauna occupied the district. In Early Tertiary times the plateau connecting Ireland, Scotland, the Faroes, and Greenland, was the scene of plateau eruptions over an area of 40,000 square miles. Horizontal tension started a series of fissures trending north-west and south-east, through which the lava poured in vast streams (pp. 50, 51). Intrusive plutonic rocks broke into the plateau from below, and now give rise to beautiful scenery, like that of the Cuillins or the Mourne Mountains (Fig. 169).

Fig. 218.—The Mountain Limestone of the Pennines faulted down beneath the Vale of Eden.

Throughout and towards the close of the Early Tertiary Period the Wealden dome was formed and the whole country elevated, the North Sea area being a plain watered by rivers from the high lands. Again the rise was greatest in the west, so that all the Mesozoic and Early Tertiary rocks were tilted to the east, and most of the river systems of Great Britain were initiated upon the inclined dip-slopes. We may attribute to this period the beginnings of the great Central Plain of England, with its subsequently developed escarpments.

Late Tertiary.—During this period the 'crags' of Norfolk and Suffolk were accumulated as shell-banks, piled up by strong currents or waves in a sea which became connected with the Arctic Ocean, whilst England was probably connected with Europe by land on the site of the Straits of Dover, and parts of the continental shelf laid bare.

Glacial and Recent.—The climate, lately tropical, gradually cooled until the Great Ice Age was ushered in, at the close of which Palæolithic man seems to have crossed the site of the Straits of Dover dry-shod. Submergence then set in, and Neolithic man found England cut off from the continent by a thin blue streak of water.

CHAPTER XVI.

Environment.

In Chapter IV. we saw that the similarity of certain groups of plants and animals in districts widely separated was due in large measure to the similarity of their *environment* (p. 29) or *surroundings* — whether upland or lowland, forest or desert, tropic or pole. At intervals also we have noted the influence of physical surroundings upon human beings, for they, no less than the lower animals and the plants, are affected by their surroundings; there is incessant action and reaction between the land and its inhabitants.

The colourings of birds and animals imitative of their surroundings are unconscious cases of adaption: the dark skin of the negro is his natural protection from the sun's rays, and so also is the tanned countenance of the white man exposed to the sun and air.

Nations frequently occupy lands marked off by natural boundaries, and the nation is maintained as such by the subtle influence of the country on the men settled therein. Nowhere is this more strikingly shown than in the case of the white settlers in North America. The cast of countenance of the typical American—descended from those men of the eastern counties of England who sailed in the *Mayflower*—is now strikingly similar to that of a Red Indian Chief. Again, the distinguishing characteristic of peoples inhabiting high tablelands is a large chest-capacity, for they must of necessity inhale large quantities of the rarefied air in order to absorb the necessary amount of oxygen; only with difficulty do strangers adapt themselves to such conditions, but amongst the inhabitants the faculty is handed from father to son. Similarly, violent changes pitilessly exterminate all those who cannot adapt themselves to new conditions. Tropical Africa is no place of abode (except upon the high plateaux) for the average White man, who merely resides there for a brief spell. The Anglo-Indian who has inured himself to the heat of India, finds the changeable climate of England a sore trial. Peoples subject to various diseases prevalent in their own land are, through a long course of adaption and the survival of the fittest, less liable to be affected than new-comers, who are more susceptible and easily succumb.

That childish disease—the measles—from which Europeans are more or less immune, swept off 60,000 of the natives of the Fiji Islands after the occupation of the latter by the English in 1874. The nomadic life of the Kirghiz is forced upon him by his surroundings, until it has become part of his nature; the steppes admit of settled life only on their most favoured portions; constant wandering is necessary to find pasturage for the numerous herds. In the spring, with horses, oxen, camels, sheep, and goats, he makes for the mountains to avoid the insect-pests; in winter he returns to the low ground. Like all nomads, he is noted for bodily endurance and sturdiness. From the forests and prairies of North

Fig. 219.—A Kirghiz Encampment.

America the Red Indian learnt his woodcraft, and gained his keen vision and appreciation of the signs and sounds of Nature. The agile pygmies of the equatorial forests can easily move about in the dense undergrowth where taller people would be helpless. The Esquimaux is adapted for life in an Arctic climate, where the struggle for existence is severe, and there is no chance of, or leisure for, culture. Living in isolated communities, and adapted for years to extremes of temperature, far away from the sea, the Russian peasant is eminently suited to be a colonizer of continental lands.

The Briton inhabits 'an island which seems specially created for

navigating the whole world ; he is a born mariner, possessed of tenacious endurance, of a bold spirit of enterprise, and of the habit of keeping a sharp lookout ; all evidently mental and moral qualities, which were indispensable to establish his primacy on the ocean, and his predominant position as trader and colonizer in all parts of the world.'* Although thus united the peoples of Britain differ much amongst themselves. In the first place, they are descended from several stocks—Celts in the West, Norsemen in the North-West, Danes, Angles, and Saxons in the East

Pictorial Agency.

FIG. 220.—BRITISH SAILORS.

and South—and therefore differ in temperament and physique. Secondly, they differ through environment. The sailor, whether from North or South, is a well-recognized type, broad and deep-chested ; so also is the agriculturalist, and yet again the somewhat slow, but steady, countryman, living far from a large town, differs from the man farming in the suburbs of a city where amusements and culture are close at hand. The men of the North are on the whole more vigorous than those of the South ; the hillsmen, living apart, are more dour and clannish than the men of the plains.

* A. Kirchhoff, 'Man and Earth,' pp. 13, 14.

In the early part of the nineteenth century, before the industrial revolution, the greatest population lay between Norfolk and the Bristol Channel; London was the only great city; agriculture and textiles were the chief occupations of the people. The modern industrial towns have grown where mechanical power or metals were handy, and therefore in the first instance on coalfields; thus manufactures were centralized by being withdrawn from the isolated positions they formerly occupied. The crowding together of workmen in towns and factories, where higher wages are obtainable than in the open healthy country, has resulted in the production of that rather small, pale, but nevertheless wiry, type—the mechanic.

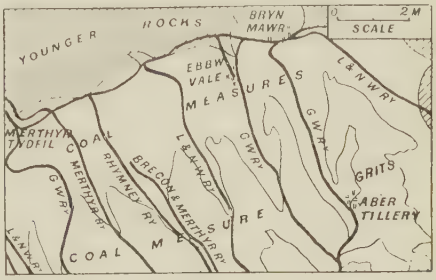


FIG. 221.—ONE RESULT OF THE INDUSTRIAL REVOLUTION.

Towns and railways on the northern fringe of the South Welsh coalfield. Notice how the lines follow the valleys.

APPENDICES.

A.

Overdeepened Valleys, Hanging Valleys, Corries, and Cirques: Ice Erosion or Protection by Ice.

The theory of ice erosion adopted (pp. 99, 125, 129-131) to account for the smooth, trough-like (U) shape of glaciated valleys, for the overdeepening of the main valley, and for the occurrence of hanging valleys, corries, and cirques, is that which is advanced by—amongst others—Penck and Brückner (Europe), Davis and Tarr (America), Andrews (New Zealand), Harker (England).

Another school of geologists and geographers, however, including many well-known mountaineers, amongst whom we may mention Bonney, Freshfield, and Garwood, offer a different explanation. They maintain that the action of glaciers is mainly protective, and that the above phenomena are due to a combination of the protective action of ice and the erosive action of water during the prevalence of certain climatic conditions.

The **ice erosion theory** was clearly stated recently by Professor W. M. Davis, of Harvard, before the Geological Society ('Glacial Erosion in North Wales,' *Quart. Journ. Geol. Soc.*, August, 1909, pp. 281-344), whilst the **theory of glacial protection** has still more recently been discussed by Professor E. J. Garwood, of London, before the Royal Geographical Society ('Features of Alpine Scenery due to Glacial Protection,' *Geog. Journ.*, September, 1910, pp. 310-336).

Supporters of the latter theory do not deny ice the power to erode, but hold the view that, in the same district, *ice erodes less rapidly than the ordinary erosive agents*—viz., weathering, wind, frost, rain, and running water—more especially in a district which is partially covered and partially free from ice, and that *ice may act relatively as a protective agent.*

Professor Davis, on the other hand, believes that erosion takes place under all parts of a glacier, but the erosion may be a slow process; *the only requirement is that it should be significantly more rapid than normal erosion.*

With regard to the **overdeepened valleys** of the Alps, Professor Garwood suggests that the main overdeepening of the trough-valley did not result from the erosion by ice during the glacial period, but from corrasion by running water during the last interglacial period (interglacial periods being warmer climatic periods during which the snow-line attained a higher level and the glaciers temporarily retreated); while the present **hanging valleys**

were still occupied to a great extent by ice, on account of their greater elevation and protection from the sun in their comparatively narrow valleys, and their rather frequent north-easterly exposure. During the warm interglacial period the stream issuing from the snout of the retreating glacier in the main valley would erode its floor with especial vigour; for, in addition to the general precipitation, it would receive in summer supplies from snow and ice melting slowly off the country, as well as from the retreating main glacier. Thus a narrow channel, originating first near the glacier's snout in a subglacial gorge, would be rapidly developed in the old valley-floor; at the same time the sides would be gradually widened by general atmospheric denudation, so that a deep **V**-shaped valley would result. All this time many of the lateral valleys, especially those upstream, would be occupied by ice, and thus largely protected. Some of the tributaries lower down would lose their ice, and become cut down to the level of (*i.e.*, establish accordant grade with) the main overdeepened **V**-shaped valley.

After the interglacial period, the glaciers once more advanced, and at first had to accommodate themselves to the narrow, overdeepened portion cut by the river during the interglacial period. By degrees they would round off and widen, and to some extent deepen, this gorge, giving the valley its final trough-like form. During this glacial advance the sides of the valley would be to some extent undercut, and the steep mouths now characteristic of many of the tributary hanging valleys may very likely be due to this process, which increased the height of the mouth above the floor of the main valley, and truncated the more gently sloping gorge which they had begun to establish at their mouths by the end of the interglacial period.

Thus the latest exposition of the protective theory is that the main glacial trough is a valley eroded by water during a mild interglacial period, and subsequently modified by ice.

Under the ice erosion theory the heads of **corries** are regarded as normal preglacial valley-heads, which have been distinctly enlarged and deepened by glacial erosion, with pronounced steepening of the walls, partly by direct glacial action, and partly by super-glacial weathering. The difficulty is that it is yet unknown exactly how glaciers can erode backwards, so as to enlarge as well as deepen their *névé* reservoirs. They are supposed to scour and pluck the rock wall and bed, and it is believed that freezing and thawing aid in prying off large blocks in the *bergschrund* around the *névé* head, as far down as weather changes can penetrate it; but this is not yet well determined by direct observation. However this may be, corrie-heads, with their steep **cirque** walls, are totally unlike valley-heads formed by normal erosive processes.

Professor Garwood, whilst admitting* that the special arm-chair form and smoothed glaciated surfaces are directly due to ice action, and that the plucking hypothesis –by keeping up a supply of angular débris—supplies

* *Geogr. Journ.*, September, 1910, pp. 313, 314.

a reasonable theory regarding the formation of corrie lakes situated in rock basins, considers that the occurrence of corries at the present day is essentially the result of the protective action of ice, the retreat and steepening of the corrie wall being entirely due to the action of frost.

It is impossible to discuss here the merits of the two theories, which are fully stated in the papers quoted above ; there are certain difficulties in both which appear to be stumbling-blocks to supporters of the opposing theory. Erosive action of ice, and the formation of rock basins by its aid, is, however, admitted by all, and Professor Garwood goes so far as to say that 'it is quite reasonable to suppose that, other things being equal, a large and deep ice-stream will erode more rapidly than a small and shallow one, and it is quite possible that a trunk-stream will erode more rapidly than its tributaries, if the whole country be glaciated. . . . It is possible even that the Alpine hanging valleys may owe some of their discordance to this cause.'*

It seems that—at present —more of the observed phenomena are explicable upon the ice erosion theory than upon the protective and climatic theory, although the latter deserves careful consideration, since it has a considerable body of very able support, especially amongst mountaineers.

B.

Coral Islands.

The statement on p. 164 that 'the polyps cannot live below depths of 30 to 40 fathoms' must be taken to apply chiefly to the true reef-builders. Corals can, and actually do, live and work at greater depths, in some cases approximating 100 fathoms. Such deep-water corals in warm latitudes may be covered by those living at intermediate depths, and these, again, by the true reef-builders. Hence a reef may be built up from a considerable depth.

Accumulation of sediment is fatal to coral life. When a reef is built up to form a broad surface, sedimentation begins to take place upon it and kill off the polyps. This result is in part due to the presence of boring organisms and sand-feeders, who break up and reduce the coral to fine mud, and in part to the presence of current- or river-borne sediment.

In many cases the waves, driven before the prevailing winds, throw sediment over the windward slopes of atoll reefs and into the lagoon, thus effectually killing off the polyps in the centre and to leeward of it. At the same time very active growth of coral takes place on the outer leeward parts, where the waters are free from sediment, and where converging and food-bearing currents sweep round the reef. The result is that the reef becomes horse-shoe shaped, the advancing and newest portions extending in the direction followed by the prevailing winds.

* *Geogr. Journ.*, September, 1910, p. 315.

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